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VASCULAR TUMORS OF BONE

A Pathological and Clinical Study of Twenty-Seven Cases

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VASCULAR tumors occur in various locations of the locomotor system and sometimes give rise to difficult problems in diagnosis and treatment. Their occurrence in muscle, tendon, nerves, joints, and bone, have been reported. Stewart and Bettin in 1924 discussed the motor significance of angiomas and called attention to some of the orthopedic problems that might arise from the presence of these tumors.

Since vascular neoplasms occur infrequently in bone, the opportunities for pathological and clinical studies are limited. As a result, the literature on the subject, especially that concerning malignant angioma, is meager, confusing, and controversial.

This contribution is the result of a study of all the vascular tumors recorded with the Registry of Bone Sarcoma of the American College of Surgeons[1]; it also includes 2 personal cases. Bucy and Capp studied 6 cases of benign angioma from the Registry and in 1929 and 1930 published excellent reports of the pathological and roentgenographical features of these tumors. Individual case reports from the group of malignant angiomas of the Registry have been published by Kolodny, Pritchard, Lutz and Pusch, and Hauser, but otherwise no comprehensive study of this whole group of malignant angiomas has been reported.

In this report an attempt is made to analyze and classify further all the vascular tumors of the Registry. In addition, an analysis of current opinions on the pathogenesis and classification of vascular tumors in general is presented in an attempt to clarify the confusion that exists concerning this controversial group of tumors.

PATHOLOGY

Vascular neoplasms are of endothelial origin and a study of the pathogenesis of these tumors must, of necessity, include consideration of endothelial tumors in general. The term "endothelioma," first introduced by Golgi, in 1869, has continued to be a subject of controversy among pathologists. Ribbert stated that it has not been shown conclusively that a neoplasm arises from endothelium. Fick protested against the use of the term "endothelioma," stating that, "Only in angiomas and tumors from angiomas can one possibly see proliferation of endothelium of a normal nature." MacCallum claimed that every unusual tumor which lacks characteristics permitting its ready recognition stands

[1]It is in the study of such rare tumors as angioma of bone that the Bone Sarcoma Registry of the American College of Surgeons proves its real value. The opportunity for one individual to study a large variety of pathological and clinical material on angioma of bone would not be possible without the aid and co-operation of such an organization. Grateful acknowledgment for the opportunity is hereby made.

an excellent chance of being labeled endothelioma, and in no case has the origin of a tumor from endothelium been proved.

Furthermore, much confusion has arisen because of the uncertainty concerning what should be called endothelium. According to Maximow and Bloom, the term should be reserved for the single layer of squamous cells which line the inner surface of the walls of the blood and lymph vessels and of the heart. MacCallum believed that only the lining cells of the blood and lymph vessels can be accepted as endothelium and stated that a few true endothelial tumors have been described which appear to arise from endothelium of blood vessels. Borst, on the other hand, interpreted the term very broadly and accepted the endothelial origin of a wide variety of tumors whose exact nature has not been determined. Ewing (16), while admitting deficiencies of our present knowledge, stated that his own experience inclined him to pursue a similar course.

It is evident, however, from an analysis of the recent literature that many pathologists today agree that the term endothelioma has had too wide an application. In their opinion the term should be restricted to tumors arising from blood and lymphatic vessels and having vasoformative characteristics. The basis for this interpretation can best be understood in the light of the modern embryological conception of the origin and development of endothelium and of the vascular system.

EMBRYOLOGY

Endothelium arises from embryonic connective tissue, the mesenchyme, which is a derivative of mesoderm. Other derivatives of mesoderm similar to endothelium are *mesothelium* which forms the lining of serous surfaces (pleura, etc.), and *mesenchymal epithelium* which gives rise to the lining of the meninges (49). These tissues, while similar in structure, have very different developmental potentialities. In the early embryonic development endothelium arises through the flattening of undifferentiated mesenchymal cells, but in the adult it is a highly differentiated tissue which grows only through proliferation of its own elements. Blood vessels and blood cells arise from the primitive endothelial cells shortly after the formation of the germ layer, probably coincidently and successively at many foci in the embryo (theory of local origin). Blood vessels form by liquefaction, vacuolation, and flattening of the primitive endothelial cells. The vessels grow by proliferation of the endothelial cells and a process of budding or sprouting takes place. The vascular endothelium loses its blood-forming power early and is transformed into the highly differentiated vascular endothelium of the adult organism. Lymph vessels also are of endothelial origin, probably arising from mesenchyme independently of blood vessels (51).

Maximow and Bloom make the significant statement that in the adult form it is often impossible to differentiate squamous cells of mesenchymal origin (endothelium) and those of ectodermal or entodermal origin. Adult cells similar in structure and arrangement may have a totally different embryonic origin and quite different developmental potentialities. For this reason, attempts to identify and classify neoplasms of the so called endothelial group have proved difficult and controversial. Only by careful consideration of these embryological factors and by a thorough study of the histogenesis as well as the morphology is it possible to diagnose accurately these tumors of endothelial origin.

HISTOGENESIS

Since vascular tumors vary greatly in their growth and development, interpretation of their histogenesis is difficult and confusing. Many excellent reports on the histogenesis of vascular tumors are found in journals devoted to dermatology and pathology. The authors, while not entirely in accord in their interpretations and conclusions, give detailed discussions of the histological and developmental variations in these complex tumors, emphasizing the importance of origin and development in their classification.

An analysis of these studies indicates that, on the one hand, there occurs a typical benign angioma of the cavernous or capillary type which is a highly differentiated structure composed of fully developed adult blood vessels. This tumor grows slowly with little evidence of cellular activity. On the other hand, there

is a rapidly growing, invasive, metastasizing tumor consisting of angioblastic tissue which is embryonic in type and very cellular. It has little structural differentiation and is definitely malignant. Between these two extremes there are tumors with varying degrees of cellular activity and differentiation, some of which may become malignant clinically, although they appear relatively benign histologically.

Simple benign angioma is a tumor composed essentially of blood vessels which grow independently and have no intimate anastomotic connection with the circulation of the part. It must be differentiated from hypertrophic granulation tissue which follows inflammation and from mere vascular dilatation seen in chronic varicosities. Benign angiomas are congenital tumors, tracing their origin to the first anlage of the vascular system in early embryonic life (63). Some writers include them in the class of congenital malformations due to developmental errors or fetal displacements without power of proliferation, such as the "hamartoma" of Albrecht. Jaffe stated, "This tumor is a hamartoma with a tendency to continuous growth." Reid in a report on arteriovenous communications expressed the opinion that many angiomas represent congenital abnormal communications between the smaller arteries and veins. However, most agree with Ribbert that angioma, though congenital in origin, is a true neoplasm which grows independently from its own vascular substance and may invade surrounding structures.

The origin and growth of benign angiomas have been studied and analyzed by many authors. Their growth resembles very closely the development of vascular tissue from primitive vasoformative cells (vascular endothelium) in the embryo. The lining cells of the tumor capillaries proliferate and extend as buds or processes, probably from multiple foci, into neighboring tissue. The tumor cells become vacuolated. The vacuoles of adjacent cells coalesce to form irregular spaces which later contain blood. In many tumors these spaces remain more or less irregular in shape (cavernous angioma); in others the lining cells become arranged as a definite endothelium and practically normal capillaries are formed (capillary angioma).

It is well known that benign angiomas often undergo spontaneous regression or healing. Thrombosis of the blood spaces occurs, followed by organization and even calcification, as indicated by the presence of phleboliths. Capillary angiomas that grow very slowly may contain vessels of adult character in which the endothelial spaces are surrounded by smooth muscle and fibrous tissue, an organoid variety of angioma (24). Such tumors offer little difficulty for recognition and classification. When the cellular activity, however, becomes such that the open spaces give way to solid masses of compact endothelium-like tissue, interpretation and classification become difficult and controversial. Invasion of adjacent tissue, local recurrence, and metastasis further complicate the picture.

A group of angiomas has been described which appears benign histologically but which behaves clinically in a manner suggestive of a malignant growth as indicated by local invasion and destruction, recurrence after surgical removal, and metastasis to distant organs. This tumor has been variously designated as benign metastasizing angioma (6), multiple mesenchymal hemendothelioma (61), malignant mesenchymal angioma (39). It presents a manifold histological appearance with transitional stages, varying between undifferentiated mesenchymal tissue and mature adult blood vessels.

There is considerable controversy in the literature concerning whether or not these apparently malignant growths can actually develop from the more benign forms, and whether the presence of multiple tumors actually represents metastases. Many authorities report cases in which metastasis occurred. Jaffe, on the other hand, doubts the existence of benign metastasizing angioma and believes that these cases of multiple tumors do not represent true metastases. It is his opinion that they arise coincidently and independently of each other from multiple congenital foci.

There is much evidence to indicate that in the malignant angiomas there is a tendency for the undifferentiated mesenchyme to form other structures of mesenchymal origin, differing from true endothelium. It may form connective tissue with a structure suggesting

sarcoma, or an epithelium-like structure with alveolar formation suggesting carcinoma. Such a process offers a logical explanation for the development of the "angioendothelioma" of bone, described by Kolodny, which is an epithelium-like tumor closely resembling metastatic carcinoma or hypernephroma, and which will be discussed in more detail.

To summarize, vascular tumors are mesenchymal in origin, probably growing from congenital rests by a process of endothelial proliferation and differentiation into blood vessels. They are usually benign and may undergo regression and healing. True malignant angiomas exist, however, characterized by rapid growth, invasion of surrounding tissues, and metastasis. Such tumors in their histogenesis tend to revert to the original primitive mesenchymal tissue, producing a varied histological picture differing greatly from that of the benign, well differentiated form. They may possess morphological characteristics of either epithelial tissue (carcinoma) or mesodermal tissue (sarcoma). There is one essential feature, however, which persists throughout the process no matter how varied or bizarre it may be, the recognition of which is essential for the diagnosis and differentiation of tumors of vascular origin. *An angioblastic tendency, as evidenced by a vasoformative process of endothelial proliferation and the formation of new blood vessels, must be present.*

CLASSIFICATION

It is evident from the foregoing description that the complex and varied histogenic and morphological picture presented by these tumors makes their classification and terminology difficult, confusing, and controversial. It is well known that the classification and nomenclature of any neoplasm has been a difficult problem, and in no other group has this been more evident than with endotheliomas. As a result, many methods and systems of classification have been advocated; some of them are inadequate and others too complex and confusing. Restricting the term endothelioma to tumors of vascular origin with a definite recognizable vasoformative tendency, simplifies the problem to a considerable degree, however.

Most pathologists classify tumors according to the predominant cell, considering both its structure and its embryonic origin. Mallory stated that the type cell is the one important element in every tumor. Ewing (16) discussed the problem as follows: "The generally accepted plan of classification and terminology which is based on histology, modified as much as possible by histogenesis, is a natural product which has become very firmly established and probably deserves to prevail against the varying prominence of embryology, chemistry, and etiology."

MacCarty proposed a terminology based on a biological conception of neoplasm, which emphasizes structure, cellular differentiation, and the significance of the "reserve cells." Pulford applied this conception to the differentiation of endothelioma, and suggested that the embryonic connective tissue cell (mesenchyme) is the "reserve cell" of the endothelium. He divided endothelial tumors into three distinct groups: angiomas, angioendotheliomas, and endotheliomas. He considered angioendotheliomas as a connecting link between the benign angiomas and the malignant endotheliomas, and reported a case in which the change from the benign to the malignant in different stages was shown. All three groups were characterized by differentiation into blood vessels.

Fraser classified vascular tumors into compact, capillary, and cavernous types, the compact representing the more cellular or malignant stage. Kettle and Ross suggested a somewhat similar division but pointed out that certain atypical forms occur in which the endothelial cell loses its characteristic features and reverts to an embryonic form, growing as a spindle cell (connective tissue), or it may develop into a flattened pavement cell with alveolar arrangement (epithelium). Busman noted a similar tendency, and considered the term endothelioma to represent a compromise between what is histogenically a sarcoma but morphologically a carcinoma. Klinge divided vascular tumors into congenital hamartomas, and genuine vascular tumors which are true neoplasms derived from the mesenchyme. He further subdivided the second group into tumors still showing the mesenchymal tissue

characteristics, which he called malignant mesenchymal angioma; and tumors which arise from the products of the differentiation of the mesenchyme, namely, the true angiomas, and the angioendotheliomas. This problem of terminology and classification of vascular tumors has also been discussed by Geschickter and Keasbey, 24; Rintelen; Rabsom; and Watson and McCarthy.

There is considerable confusion and vagueness in the use of the terms angioendothelioma and angiosarcoma which have been loosely applied to various types of malignant tumors of extreme vascularity. The problem is complicated by the fact that in certain neoplasms there is an excessive development of blood vessels as a result of venous stasis or nutritional demands. These are not true vascular tumors, although their vascularity has been indicated by the term "angiomatosum" (16). Many of the earlier reports of malignant angiomas are tumors of this type. Ribbert stated that malignant angioma (angiosarcoma) and angioendothelioma are difficult to differentiate, and that malignant angiomas may very well be called angioendothelioma because in both there is proliferating endothelium which produces vascular channels and invades surrounding structures. Winkler considered angiosarcoma, endothelioma, perithelioma, and angioendothelioma, and sarcoma of vascular tissue as synonymous terms. Borst suggested the term angioblastic sarcoma or malignant angioblastoma as indiciating a malignant tumor in which the characteristics of the normal vascular tissue are more or less apparent, although distorted and atypical. Ewing (16) stated that the present tendency is to limit the term angiosarcoma to cellular angiomas in which the unit is the vessel and not the endothelial cell. He reserved the term angioendothelioma for vascular tumors in which the endothelial cell predominates. In discussing the malignancy of vascular tumors, Geschickter and Keasbey (24) stated, "The pathologic conception of malignant tumors of blood vessels (endotheliomas) has been constantly narrowed. Many of the lesions formerly described as hemangioendotheliomas, perithelioma, cylindroma, and perithelial angiosarcoma may be reclassified as metastatic lesions of the thyroid or kidney, or as secondary deposits from nonpigmented malignant melanomas."

It is suggested from this study that a simple and workable classification is one which considers vascular tumors as endotheliomas accompanied by a definite vasoformative tendency with endothelial proliferation and new blood vessel formation. These tumors may be classified as: (1) benign angioma, a slow growing, highly differentiated tumor, congenital in origin, with definite well formed blood vessels and an innate tendency to regress and heal; and (2) malignant angioma, a more cellular and compact growth with active endothelial proliferation and invasiveness, showing a tendency to revert to its primitive mesenchymal structure. In certain cases of malignant angioma it is possible to differentiate two subdivisions, namely the *angioendothelioma* and the *angiosarcoma*. The angioendothelioma shows a rather marked cellular proliferation, and in its tendency to revert to a primitive mesenchymal structure the cells assume a cuboidal appearance and alveolar arrangement closely resembling epithelial tissue. Nevertheless, new blood vessel formation is evident. In angiosarcoma the vasoformative tendency is much more prominent. This new vessel formation is the predominant feature of the tumor, and enables it to be more easily identified as a true vascular tumor.

These terms are rather indefinite and ill defined, tending to merge one into the other. Structures suggesting both types may be found in different areas of the same tumor, and the terms are frequently used synonymously. Certain clinical features as well as the histogenesis and morphology must be considered in the final analysis. The special clinical and pathological features which apply in the identification and classification of vascular tumors occurring in bone will be considered later.

VASCULAR TUMORS OF BONE

Primary vascular tumors of bone are not common but probably occur more frequently than reported cases indicate. In the benign forms they are slow growing or regressive, and because they are symptomless, they may be unrecognized. In the more malignant types

they present such a varied clinical course and pathologic appearance that they are often incorrectly diagnosed. On the other hand, many tumors of bone have previously been included in this group which, in the light of further analysis, do not belong there.

REVIEW OF LITERATURE

Very few thorough, comprehensive studies of the pathological and clinical features of vascular tumors occurring in bone have been reported in the literature. Most contributions have been case reports or have dealt only with certain special features of these tumors, such as the roentgenographic considerations. Many of the older studies are of little value as the majority of the cases reported were highly vascular tumors of various types other than true angiomas.

Hitzrot in 1917 reported a case of cavernous hemangioma of the upper end of the humerus and included the first roentgenograms published on this tumor. He reviewed the literature to 1917. In 1930 Bucy and Capp (10) gave an excellent report on primary angioma of bone with special reference to roentgenographic diagnosis. They reviewed all reported cases to date and added 8 cases, 6 of which were from the Registry of Bone Sarcoma of the American College of Surgeons. Geschickter and Masseritz (27) in 1938 again brought the literature up to date and included 4 additional cases.

Cases of angioma of vertebrae with clinical symptoms have been reported with increasing frequency in recent years. Many have been diagnosed before operation by the characteristic roentgenographic appearance. Topfer in 1928 found angioma of the vertebrae in 257 cases of 2,154 postmortem examinations of the vertebral column, 11.9 per cent. None of the lesions found at autopsy had apparently produced clinical symptoms.

Many cases of angioendothelioma are described in the literature, some of which are included under the term endothelioma. Endothelioma of bone was probably first described by Lucke in 1866. Marckwald in 1895 reported a rather remarkable case of multiple intravascular endothelioma in most of the bones of the skeleton. Howard and Crile in 1905 analyzed 19 previously reported cases and added 4 of their own. Many more cases of single and multiple endotheliomas of bone have been reported, but no effort has been made to enumerate all of them here. Hirsch and Ryerson in 1926 gave a complete list of all reported cases. After a critical analysis of these cases they concluded that in many of them doubt exists regarding the thoroughness and completeness of the postmortem examination. In their opinion many of the tumors reported as endotheliomas were no doubt metastatic carcinoma from primary lesions not found at autopsy.

Kolodny in 1926 reported 2 cases from the Registry of Bone Sarcoma (Cases No. 154 and 291). He discussed the features in detail and defended the use of the term angioendothelioma of bone as a distinct clinical and pathological entity. Since Kolodny's contribution, cases have been reported by Pritchard (1931), Barry (1932), Warner and Singleton (1933), Brailsford (1934), and Lutz and Pusch (1939). Some of these cases are registered with the Registry of Bone Sarcoma and are included in this study (B.S.R. Nos. 154, 291, 1040, 2156).

True angiosarcoma of bone is probably a rare tumor as only a few cases have been reported in the literature. There is much confusion concerning the use of the term, and many of the earlier cases were no doubt vascular sarcomas and not true malignant angiomas. Freilich and Coe in 1936 published a case of angiosarcoma of the scapula and reviewed all cases previously included in the literature. In addition to their own they listed 3 cases involving bone: one of the ribs (70), one of the femur (67), and one of the clavicle (48). Pulvertaft in 1938 reported a malignant vascular tumor of the sacrum which he called a hemangioblastoma, classifying it with Kolodny's angioendothelioma of bone. The photomicrographs accompanying the report show a degree of blood vessel proliferation more characteristic of angiosarcoma. Delitch in 1939 described a case of primary angioma of the tarsal and metatarsal bones with sarcomatous degeneration. The histological description and drawings strongly suggest that this case can be classified as an angiosarcoma. There is also a case of angiosarcoma of the os calcis reported

TABLE I.—BENIGN ANGIOMAS OF BONE

No.	Registry of bone sarcoma No.	Sex	Age	Single or multiple	Bones involved	Roentgenographic appearance	Treatment	Results
1	153	F.	43	S.	Ileum	Sunburst	Radiation	Symptom free 9 yrs.
2	178	M.	?	S.	Mandible	Not given	Curettement and toxins	Symptom free 5 yrs.
3	230	F.	55	S.	Cranium	Sunburst	Excision	Symptom free 13 yrs.
4	249	M.	35	S.	Tarsal scaphoid	Cystic	Curettement	Symptom free 11 yrs.
5	662	M.	20	S.	Cranium	Sunburst	Excision	Death at operation
6	849	M.	20	S.	Ulna distal end	Cystic	Excision	No recurrence 7 yrs.
7	940	F.	62	M.	Vertebrae 3d, 4th, 5th, 6th thoracic	Typical vertical striations	Laminectomy and radiation	Symptom free 5 yrs.
8	941	F.	49	S.	Scapula	Sunburst	Biopsy cast	No recurrence 8 yrs.
9	1361	M.	15	M.	Tibia, fibula, and tarsus	Fusiform expansion, cystic	Excision	Symptom free 7 yrs.
10	1588	M.	40	S.	Vertebra 4th dorsal	Vertical striations	Laminectomy and radiation	Symptom free 6 yrs.
11	1882	F.	24	S.	Tibia, distal end	Calcified mass	Curettement	No recurrence 2 yrs.
12	Author's case	F.	52	S.	Base of 3d metacarpal	Cystic	Curettement	No recurrence 9 yrs.

in the paper of Geschickter and Masseritz (27). In 1940, Hauser reported a case from the Registry (B.S.R. No. 1530) in which the femur was primarily involved. This case is included in this study.

ANALYSIS OF CASES

Thirty-eight cases of tumors were studied, 36 of which were from the Registry of Bone Sarcoma of the American College of Surgeons. Eleven of the latter were eliminated, however, because either the data were insufficient to warrant a diagnosis, or the preponderance of evidence was against the diagnosis of vascular tumor, as indicated by the majority of opinions expressed by the various pathologists who studied the cases for the Registry. Confirmation of the diagnosis in each case was obtained from several local pathologists who assisted in the histological study of these cases.

In the revised classification of bone tumors proposed by Ewing (17), and adopted by the Registry of Bone Sarcoma of the American College of Surgeons in 1939, vascular tumors are classified as follows:

"IV. ANGIOMA SERIES

Benign	*Malignant*
1. Cavernous angioma	3. Angioendothelioma
2. Plexiform angioma (Sun-ray radiological type)	4. Diffuse endothelioma (Ewing's tumor)"

In this study the above classification has been generally followed except that diffuse endothelioma (Ewing's tumor) has not been included. The origin of this tumor is still controversial and not all authorities are willing to accept Ewing's theory of vascular origin. Also adequate studies of this group already have been reported. In addition, an attempt has been made by the author to divide further the malignant angiomas into two subdivisions: (1) angioendothelioma and (2) angiosarcoma, as previously suggested. Certain structural differences which seem to justify such a division will be discussed in more detail in the section devoted to malignant angiomas of bone.

BENIGN ANGIOMA (TABLE I)

There are 12 cases of benign angioma in this group. The sexes are equally divided, and the ages range from 15 to 62. Six of these cases have been previously reported by Bucy and Capp. The flat bones of the skull, pelvis, and shoulder are involved most frequently, the long bones of the extremities being next in frequence. The small bones of the hands and feet are infrequently involved.

The literature tends to confirm this order except that the large number of cases of angioma of vertebrae which have been recently recorded indicates that probably the vertebrae are the most common site for these tumors.

Clinical symptoms. The clinical signs manifested by benign angioma of bone are variable and not pathognomonic. Many tumors are symptomless or produce symptoms secondarily by pressure and growth. In the vertebrae the tumor often produces pressure on the cord with neurological signs of varying degree. Vertebral angiomas associated with epidural angioma have been reported occasionally.

Roentgenographic appearance. Perman, Bucy and Capp (10), Geschickter (23, 27), and Nemenov have called attention to certain signs appearing in the roentgenograms that are more or less characteristic and aid in the diagnosis of benign angioma. In the vertebrae the picture is characteristic and even diagnostic. There is an irregular absorption of bony trabeculae and a thickening of the remaining vertical trabeculae with resulting parallel, vertical striations and loss of the normal homogeneous structure. Not uncommonly these trabeculations extend into the vertebral arches (Fig. 1, a).

Involvement of the flat bones often presents a characteristic "sunburst" appearance in the roentgenograms (plexiform angioma). Bony trabeculations radiate from a common center, usually at right angles to the plane of the bone. Cases presenting this appearance have been reported by Anspach, and Kaplan and Kanzer. Four such cases are included in this series (Fig. 2, a).

The roentgenographic appearance of angioma of long bones has been described as the unique "soap bubble" effect. There are coarsely multiloculated areas of rarefaction which expand the shell of bone to paper-like thinness, giving a cystic appearance resembling giant cell tumor. In angioma, however, the loculations are somewhat smaller and within them there is a fine fibrillary framework. The cortex usually is not expanded as in giant cell tumor or bone cyst (Fig. 3, a).

These roentgenographic effects are determined largely by the bone involved and rapidity of the growth of the tumor. However, the roentgenogram is not always characteristic or diagnostic.

Pathological findings. Bucy (9) described the histological structure of benign angioma of bone in considerable detail. With the exception of one case in this series the tumors are cavernous in type composed of large endothelium lined spaces filled with blood (Figs. 1, b; 2, b). The remaining case can be classified as a capillary angioma (Case No. 849). In none of the cases is there evidence of unusual endothelial proliferation, and mitotic figures are not found. The stroma is loose fibrous connective tissue and is variable in amount. Bone destruction takes place as the result of reaction to growth and not to invasion by the tumor mass. Calcification is present in one case (B.S.R. No. 1882).

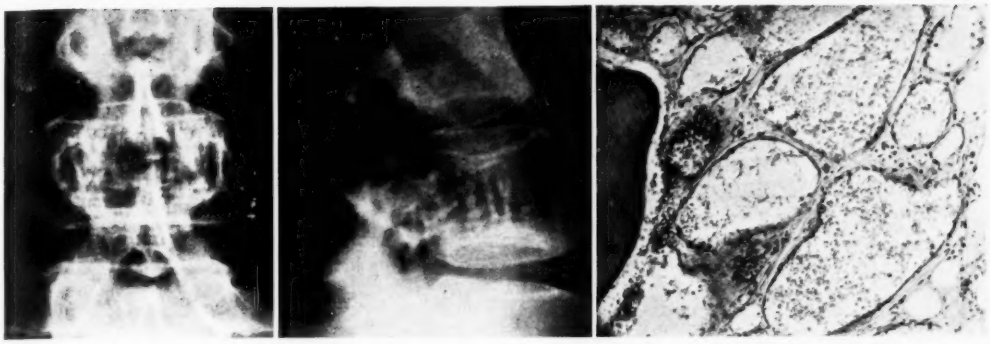
Treatment and results. The majority of cases in this series have been treated quite successfully by irradiation or operation or by both. Wherever possible, as in the cranium or bones of the extremities, resection or curettement and cauterization have proved satisfactory. The danger of severe hemorrhage from operation must be considered, especially in operations on the cranium and spine. In one case (B. S. R. No. 662) death occurred as a result of shock and hemorrhage following removal of the growth in the cranium.

Karshner and associates attributed the high mortality in laminectomy to overenthusiastic surgical efforts. They warned against opening the dura or attempting to remove more of the tumor mass than is necessary to relieve pressure. They also pointed out that although high voltage roentgen-ray therapy is recommended as a postoperative measure, it would seem inadequate and hazardous to use it alone when there is compression myelitis. Irreparable damage to the cord may occur before any beneficial effect can be anticipated.

Meyerding found angioma of bone to be somewhat radiosensitive and under moderate dosage, repeated at regular intervals for a number of months, it gradually regresses until healed. In several of the cases reported by Geschickter and Copeland (23), cures were obtained by curettage followed by chemical or thermal cauterization. With these methods of treatment the prognosis is excellent, and amputation should rarely be necessary.

MALIGNANT ANGIOMA (TABLE II)

The histological variations evident in a study of malignant angiomas suggest that



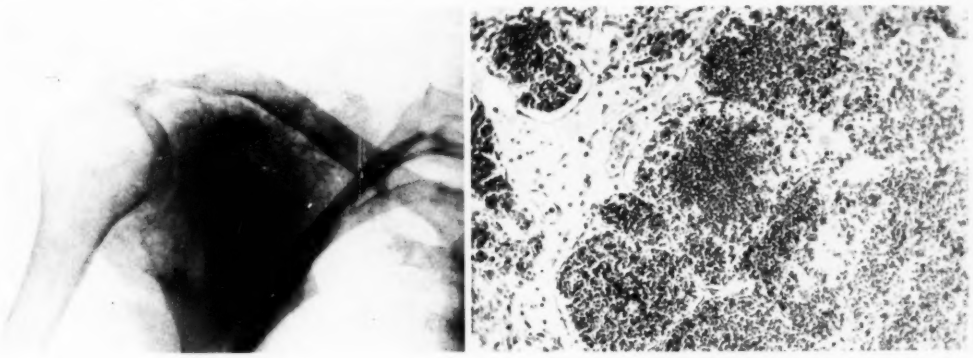
a b

Fig. 1. a, Benign angioma of the second lumbar vertebra. The vertical striation is diagnostic. b, Cavernous angioma of vertebra (B.S.R. No. 940). The blood filled channels between the bone trabeculae are very large.

they might be divided, as previously stated, into two groups, the angioendothelioma and the angiosarcoma. It must be appreciated that such a division cannot be too rigidly applied. It is very difficult or occasionally even impossible to determine into which of the two groups some of the cases should be placed. This difficulty is evidenced by the wide difference of opinions expressed by the pathologists who examined these cases for the Registry of Bone Sarcoma. Because of these difficulties in classification, all angioblastic tumors in this group are tabulated under the general heading of malignant angioma. Wherever possible, an attempt is made to indicate whether or not the tumor is considered an angioendothelioma or an angiosarcoma (Table II.)

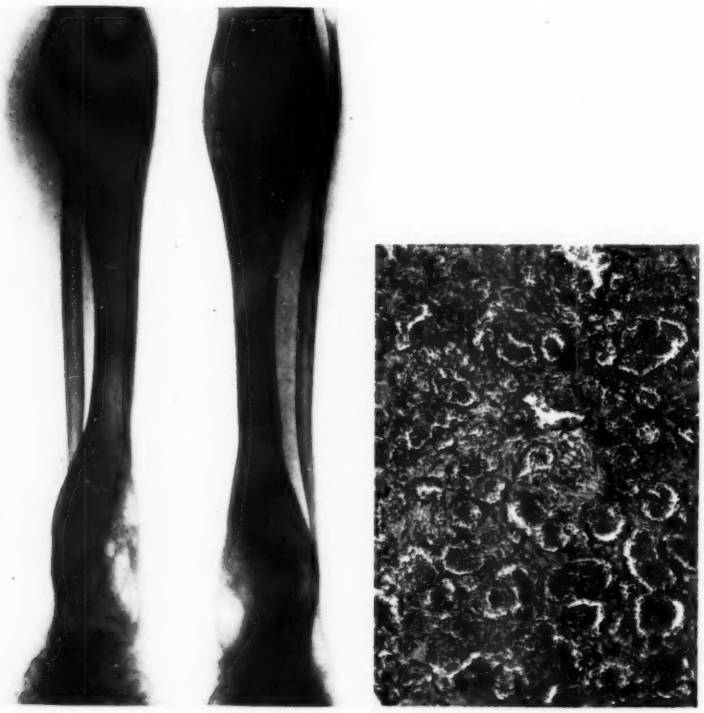
There are 15 cases in this group of malignant angioma. The sexes are almost equally represented, 7 females and 8 males. The age limits are younger than in the benign angiomas, ranging from 3 to 53 years, the majority being in the second and third decades. The long bones are the most frequently involved, although in 3 cases the tumor is primary in the bones of the hands and feet, and in 1 instance in the ileum. Multiple lesions are present in 6 cases, the multiplicity being a part of a widespread metastasis in 3. It is impossible, therefore, to ascertain accurately which is the primary lesion in some of these multiple cases.

Amputation was performed in 9 cases with apparent cure in 4, and 1 has been too recent to express an opinion. Exploration and cu-



a b

Fig. 2. a, Benign angioma of scapula (B.S.R. No. 941). The "sunburst" appearance is diagnostic. b, The large endothelial lined venous sinuses lie between bone trabeculae. Amount of connective tissue framework is small.



a b

Fig. 3. a, Multiple angioma of tibia and tarsus (B.S.R. No. 1361). Fusiform expansion with multiloculated rarefaction of both the proximal and distal ends of the tibia is present. The tarsal bones present a cystic appearance. b, The vascular spaces are numerous and closely packed with a very slight amount of connective tissue stroma.

rettement were carried out in one case with no recurrence after 10 years. Ten patients were treated by radiation, death occurring in 6. In the 4 surviving patients treated by radiation, amputation was done in all 4. In 1 case an apparent cure was brought about in the primary lesion, but the tumor recurred in an adjoining bone 5 years later and amputation was necessary.

Death following metastases to viscera and other bones occurred in 8 cases. In 1 case death resulted from intercurrent disease 6 months after amputation.

Angioendothelioma. Kolodny stated that most pathologists hesitate to admit that angioendothelioma of bone is a pathological entity. He pointed out the reasons why this tumor should be considered an entity, and defined the term as "a malignant tumor of the vascular system of bone with a typical microscopic structure and a definite origin from the endothelial lining of the vessel wall." However, he stressed that in every case of suspected angioendothelioma, the possibility of a metastatic origin must be considered and eliminated.

The histological appearance of these tumors as described by Kolodny resembles an adenomatous growth with the tumor cells arranged in alveoli and tubules. The tumor cells are large, polyhedral, or sometimes cylindrical in shape with well defined cell membrane and pale vasicular nuclei and minute nucleoli. The alveoli have a lumen sometimes filled with blood.

Hirsch and Ryerson, in a study of bone metastases from primary carcinoma of the lung

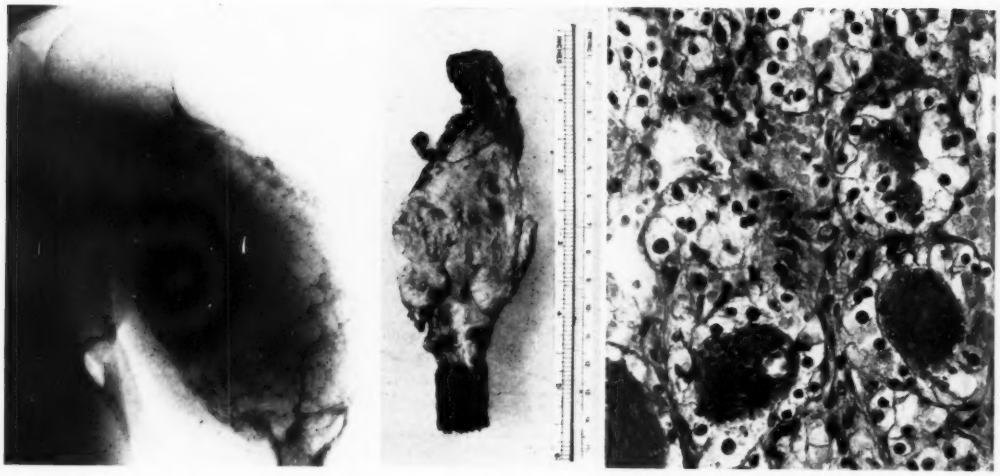
TABLE II.—MALIGNANT ANGIOMAS OF BONE

No.	Registry of bone sarcoma No.	Sex	Age	Single or multiple	Primary bone involved	Classification	Treatment	Results	Metastasis	Necropsy
1	83	F.	13	S.	Humerus	Angioendothelioma	Curettement	No recurrence 10 yrs.	None	—
2	154	F.	10	S.	Tibia	Angioendothelioma	Amputation	Died 4½ yrs.	Chest and skull	No
3	291	F.	45	M.	Entire skeleton	Angioendothelioma	Radiation	Died 8 mos.	Viscera	Yes
4	798	M.	17	S.	Femur	Angioendothelioma	Radiation, amputation	Died 2 yrs.	Viscera	No
5	1007	M.	47	M.	Tarsus	Angioendothelioma	Radiation, amputation	Died 2 yrs.	Bone and viscera	Yes
6	1040	M.	30	M.	Radius and carpus	Angiosarcoma	Radiation, amputation	No recurrence 10 yrs.	None	—
7	1174	F.	38	S.	Femur	Angiosarcoma	Radiation, amputation	No recurrence 3 yrs.	None	—
8	1428	F.	24	S.	Fibula	Angiosarcoma	Excision, radiation	Died 3 yrs.	Lungs	No
9	1482	M.	30	M.	Rib?	Angiosarcoma	Radiation	Died 5 yrs.	Bone and viscera	Yes
10	1530	F.	48	M.	Femur	Angiosarcoma	None	Died 2 mos.	Bone and viscera	Yes
11	1912	M.	?	S.	Metatarsal	Angiosarcoma	Radiation, amputation	Died 2 yrs.	Lungs	No
12	2126	M.	38	S.	Ileum	Angiosarcoma	Exploration	Alive after 1 yr.	None	—
13	2156	F.	53	S.	Humerus	Angioendothelioma	Radiation, amputation	No recurrence Died of heart failure 6 mos.	None	No
14	2182	M.	50	S.	Tibia	Angiosarcoma	Amputation	No recurrence 3 mo.	None	—
15	Author's case	M.	3	M.	Tarsus	Angiosarcoma	Curettement, radiation, amputation	No recurrence 13 yrs.	None	—

reviewed the problem of so called multiple endotheliomas of bones. They were inclined to cast doubt on the correctness of many such reported cases. In their opinion the assumption of multiple primary foci in bone as an explanation of coincident tumors in various parts of the skeleton seems to be due to the failure of finding a small primary carcinoma on postmortem examination or to inability to distinguish the primary group from the secondary in the presence of many tumors in different tissues. As a solution to the problem, they urged careful and thorough postmortem examination supplemented by a thoughtful interpretation of the changes thereby demonstrated.

Geschickter and Copeland (23) did not mention angioendothelioma of bone as a clinical entity in their monograph of bone tumors. Furthermore, Geschickter and Masseritz (26) in a study of Ewing's tumor stated that in the series they did not see a case of bone tumor in which the diagnosis of angioendothelioma was justified. They said it is readily understood how metastatic hypernephroma, anaplastic and mucoid forms of carcinoma, and angiosarcoma can possibly be diagnosed as angioendothelioma. Yet, in the discussion of a case of angioendothelioma reported by Lutz and Pusch in 1939, Geschickter (22) made this significant statement:

"A few years ago it would have been embarrassing to open this discussion because I was convinced there wasn't any such thing in bone as angioendothelioma; but today we have to admit that all forms of pathologic involvement of the bone of a neoplastic character have not been described. . . . The only objection to the term endothelioma is that it is so widely misused. My conception is that these tumors arise from primitive mesoderm around joints and may be found in bone. They are not metastatic, they are moderately radiosensitive but not radio curable, and these patients should have the benefit of radical surgery."



a b c

Fig. 4. a, Angioendothelioma of humerus (B.S.R. No. 2156). A large cyst-like expansion of the shaft with numerous thin lacy trabeculations and thinning of the cortex is evident. b, Gross specimen split longitudinally. The pale tissue composing the bulk of the tumor was necrotic. c, The large clear cells with vesicular nuclei are arranged in alveoli, some of which have lumen filled with blood.

The loose manner in which the term angioendothelioma has been used by some authorities only adds to the confusion of identifying this controversial tumor. Some use it simply as a descriptive term indicating a certain histological structure; with others it designates a definite pathological and clinical entity. Connor, for example, employs the term to describe an unusually vascular type of diffuse endothelioma (Ewing's tumor). Kolodny, on the other hand, indicates a definite clinical entity quite different from Ewing's tumor. Many pathologists today do not accept Ewing's tumor as a true endothelioma of vascular origin, but believe it to be a neoplasm originating from the reticulum or the lymphoid cells. Ewing (16, 17), on the other hand, recognizes a definite angioblastic tendency in this tumor and considers it to be a form of capillary angiosarcoma or endothelioma arising from the blood vessels of bone marrow. He classifies Ewing's tumor, therefore, as a form of malignant angioma. He reserves the term angioendothelioma to designate a more vascular type of endothelioma, which he describes as a solitary cystic tumor, usually developing in the ends or shafts of the long bones. "The structure presents large cuboidal or cylindrical cells arranged in cords or pseudoalveoli and enclosing freely circulating blood. The cells are large with clear cytoplasm, sharp cell membrane, and small nucleus." He further states that a similar structure may be seen in liposarcoma or in metastatic carcinoma of kidney or adrenal, which tumors must be excluded before the diagnosis of angioendothelioma can be established.

Rost wrote at length on the histological differentiation between primary bone endothelioma and hypernephroma. He believed that the two can be distinguished by a purely morphological analysis, emphasizing the importance of the relationship of the tumor cells to the surrounding connective tissue stroma in differentiating the two. In endothelioma they are intimately related to the underlying structure. In hypernephroma the connection is loose, and there is usually a space between the cells and the connective tissue surrounding the alveoli. Kolodny and Ewing (16) also have emphasized the importance of this relationship of the tumor cell to the surrounding connective tissue stroma in the differentiation of these two tumors.

This résumé of current opinions indicates that the question whether angioendothelioma

a b c

Fig. 5. a, Angiosarcoma of femur with metastasis (B.S.R. No. 1530). The primary lesion is a large rarefied area just above the condyles which has broken through the cortex anteriorly. The small discreet, oval lesions in the midshaft are probably metastatic. b, Metastatic lesions in the ribs are seen. c, The lesion is composed of irregularly arranged vascular spaces, lined by large endothelial cells and surrounded by a fibrillar network containing large numbers of similar cells. Mitotic figures are seen. New blood vessels evident in the section are characteristic of this tumor.

of bone exists as a pathological and clinical entity is still a controversial one, although the evidence suggests that such a tumor of bone does occur. The problem of diagnosis is especially difficult when the skeletal lesions are multiple, since it is often difficult or impossible to ascertain which is the primary focus. In such cases metastatic lesions from a primary carcinoma or hypernephroma cannot be ruled out absolutely without a complete and careful postmortem examination. In single lesions the problem is not so difficult. If the patient remains well for several years following amputation or excision, it is presumptive evidence that the lesion is primary in bone.

Six cases in this group of malignant angiomas have been designated angioendotheliomas, although the diagnosis in some of them might be open to question because of the difficulty in distinguishing them histologically from metastatic carcinoma or hypernephroma. Postmortem examination was done in 3 of the cases, however, and no evidence of primary carcinoma was found. Metastasis and death occurred in 4 of the 6 cases. In the 2 cases that were not fatal, the proximal half of the humeral shaft was involved in both. One of these (B.S.R. No. 83) was treated by curettage and cauterization with no recurrence 10 years later. In the other case (B.S.R. No. 2156) treatment consisted of radiation and finally amputation. Death occurred 6 months later from coronary occlusion but without evidence of recurrence. Postmortem examination was not made.

Geschickter's (22) and Ewing's (16) statement that angioendotheliomas are usually found in the ends of the long bones is confirmed by this study. Examination of the roentgenograms shows a varied appearance which cannot be called characteristic or diagnostic. All show rarefaction and destruction, and rarely bone production. Some reveal cystic expansion with well defined septa which Brailsford described as characteristic of angioendotheliomas. Such an appearance, however, is not typical of the cases in this series (Fig. 4, a).

An analysis of the clinical symptoms reveals nothing significant or diagnostic. The symptoms vary according to the location of the le-

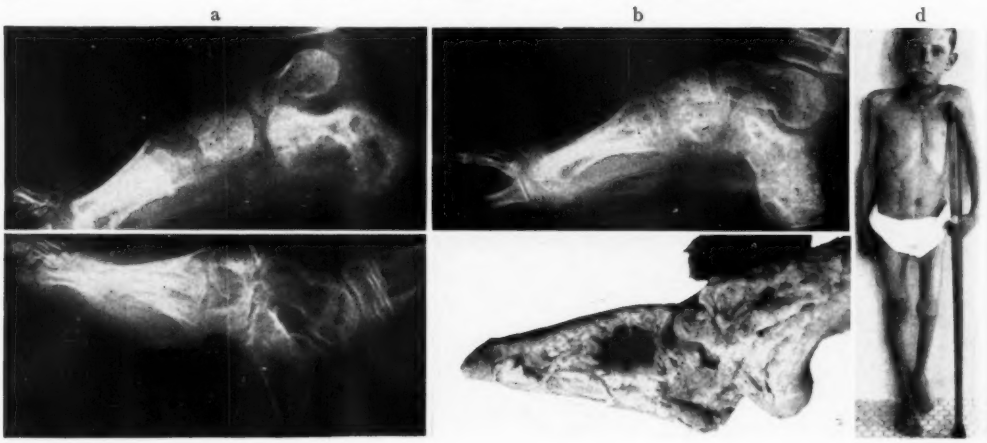


Fig. 6. a, Angiosarcoma of calcaneous (author's case). January, 1926. There are multilocular cystic areas, involving the central portion of the calcaneus and breaking through the cortex along the inferior border. b, Same case, 1930. Considerable regeneration has taken place in the calcaneus, but some cystic areas still remain. The cuboid is involved. Note the marked cavus deformity. c, Same case, 1932. Wedge osteotomy and arthrodesis attempted one year previously. The calcaneus is healed. There is new involvement in the navicular, cuboid, and cuneiform bones. d, Photograph of patient, 4 years after first operation. Note the marked shortening (6 inches) and disuse atrophy of the right lower extremity. e, Sagittal section of amputated specimen. (Compare with roentgenogram, Fig. 6, c.) Note the dark colored, angiomatous growth in the midtarsal region. The calcaneus appears essentially negative. f, Tissue from calcaneus removed at first operation in February, 1926. Tumor is quite dense and cellular, being composed of many small blood spaces, lined with and surrounded by large proliferating endothelial cells. Blood pigment is scattered throughout. The marked endothelial proliferation with compression of the blood channels suggests a malignant angioma (angiosarcoma). g, Tissue removed from the midtarsal region of the amputated foot, October, 1933. A marked change is noted in the structure as compared with that seen in Figure 6, f. The blood spaces are much larger and the tumor cells are smaller, less densely packed, and not so proliferative. Granules of blood pigment are still present. The tumor now presents characteristics more suggestive of benign capillary angioma.

sion, the rapidity of growth, and the degree of malignancy, all of which conditions vary to a great extent.

The microscopic appearance of these tumors is varied but in all there is a suggestion of an alveolar arrangement of cuboidal cells surrounded by a connective tissue framework which closely resembles carcinoma or hypernephroma. Some of the lumina of the alveoli may contain blood cells. New blood vessel formation is evident in all cases, however, the vasoformative tendency is not nearly so predominant a feature as it is in angiosarcoma (Fig. 4, c).

Angiosarcoma. There seems to be almost as much confusion associated with the angiosarcoma group of vasculartumors as with angioendothelioma. The term is loosely applied, and is often used synonymously with angioendothelioma. The interpretation concerning which of the tumors belong in this classification is very broad.

According to Ewing (16) the term was first employed by Kolacszek and Waldeyer to designate all tumors originating from blood or lymph vessels, including that group of tumors known as "perithelioma." Ewing describes perithelioma of bone as a soft, vascular tumor, often pulsating, which is identical with the solitary cystic type of angioendothelioma. He is of the opinion that it is better to limit the term angiosarcoma to the cellular and malignant forms of angiomas and not to include angioendothelioma or perithelioma. Freilich and Coe agree with this interpretation and state that the term should be restricted to neoplasms that show distinct vasoformative tendencies. Their histological description of a case of angiosarcoma involving the scapula is given as follows:

"The tumor is of great cellularity, and in many areas the cells are densely packed together. There are short oval nuclei with a distinct nuclear membrane and moderately rich in medium-sized chro-

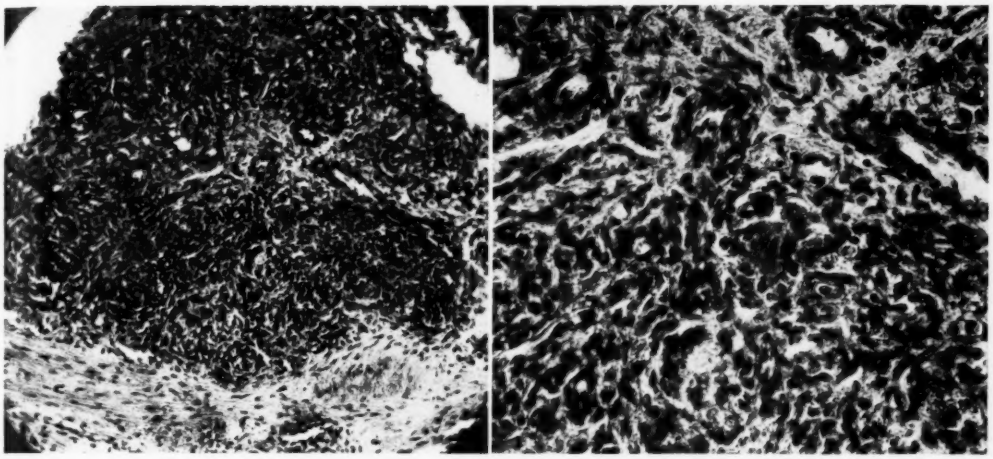


Fig. 6f

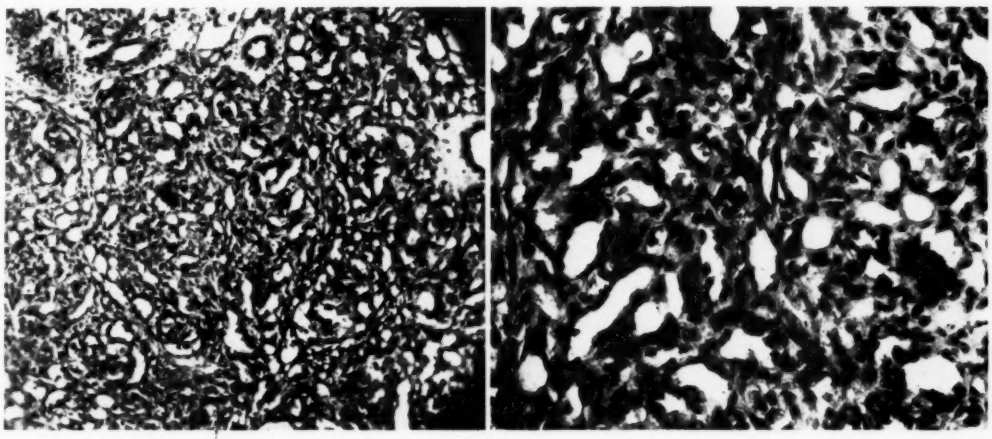


Fig. 6g

matin granules. Mitoses are frequently found. The cellular areas are traversed by a varying number of wide, thin walled blood spaces which are lined by flat endothelium. In places, the blood vessels are very numerous and may even excel the strands of cells. The vessels are now less sharply differentiated from the cells surrounding them and transitions can be found between the cells in solid strands and those lining the blood spaces. Since the undifferentiated neoplastic mesenchyme reveals distinct vasoformative tendencies, the microscopic diagnosis is angiosarcoma" (Jaffe).

Telangiectatic sarcoma has been designated by some as a form of angiosarcoma, as in a case reported by Hodges, et al. In the classification of the Registry of Bone Sarcoma, however, this tumor is placed under the osteogenic sarcomas. Ewing (17) has recently discussed its classification as follows:

"Telangiectatic sarcoma, a form of malignant bone aneurysm, is a very characteristic bone tumor, but its exact origin and relation to other bone sarcomas has not been satisfactorily determined. There is considerable evidence suggesting that this process belongs with the tumors of blood vessels of bone and is a cavernous angiosarcoma. . . . Further data seem necessary before the true nature and relations of the so called telangiectatic bone sarcoma can be determined, and these data should relate to the part played by blood vessels in the origin and growth of

other osteogenic sarcomas. Their clinical connections with other malignant bone tumors seem to warrant their retention, for the present, in any complete group of bone sarcomas."

The term angiosarcoma is used in this study to indicate a malignant neoplasm showing proliferating vascular endothelium with new blood vessel formation in which the vasoformative tendency is the predominant feature (Fig. 5, a). Nine cases have been classified as angiosarcoma on the basis of this histological picture. Metastases and death occurred in 4. Amputation was performed in 5, 4 of which were alive without evidence of recurrence on last report. The author's case has been followed 13 years. Excision was done in 1 case in which the primary lesion was in the fibula, death with pulmonary metastases occurring 2 years later.

The clinical and roentgenographic signs are in no way distinctive, being of little value in differentiating angiosarcoma from other malignant bone tumors. Since the diagnosis is made entirely on pathological findings, biopsy is of great value.

The results in this series indicate that angiosarcoma and angioendothelioma are only moderately radiosensitive, in contradistinction to Ewing's tumor. Early surgery, such as excision or amputation, supplemented by radiation offers the best possibilities for cure.

REPORT OF A CASE OF ANGIOSARCOMA OF TARSAL BONES

P. S., white male, aged three years, was first seen on January 22, 1926, complaining of pain in the right heel. His father stated that he limped when he first began to walk. The symptoms gradually increased in severity until he was unable to bear any weight on the affected leg. There was no history of injury.

The patient was a rather frail boy who refused to bear any weight on the right foot. Examination of the right lower extremity revealed atrophy of the thigh and calf muscles. Any attempt to move the foot caused pain, localized in the mesial side of the heel. There was fullness on the mesial and plantar aspect of the heel. These areas were very tender to pressure, especially over the plantar surface of the heel posteriorly. The right knee was held in slight flexion, and an attempt to straighten the knee elicited pain in the foot. The physical examination was otherwise negative.

Roentgenograms (Fig. 6, a) of the right foot showed a cystic area involving the calcaneus. Inferiorly, the process had broken through the cortex.

Treatment. A tentative diagnosis of tuberculosis of the calcaneus was made, and the patient was hospitalized. The foot was immobilized in a plaster-of-Paris cast extending from the toes to midthigh. He was kept in bed, and heliotherapy was started. Laboratory findings were essentially negative, including the tuberculin and Wassermann tests. Instead of improving, the pain increased. It was necessary to remove the cast 3 weeks later. Examination indicated that the infiltration and swelling beneath the heel had increased, and the foot was more tender. It was therefore decided to explore the lesion by operation.

On February 20, 1926, under ether anesthesia, an aspiration was attempted without success. The calcaneus was then exposed by a posterolateral flap incision. The periosteum was intact, but there was an opening in the bone cortex on the plantar surface of the calcaneus extending into a large cystic cavity. The cavity was filled with purplish red, friable tissue, resembling granulation tissue. Several small pieces of bone were lying free in the cavity. The edges of the opening were irregular and overhanging. The lesion was very vascular, bleeding freely when touched. The cavity was thoroughly curetted and then cauterized with phenol. It was necessary to pack the wound to control hemorrhage. The skin wound was loosely closed with interrupted silk worm sutures.

Convalescence was uneventful. The gauze pack was removed under gas anesthesia on the 3d day without further hemorrhage. The sutures were removed on the 10th day, the wound being apparently healed.

Pathological report. A direct smear showed no organisms, and the culture was negative. Two guinea pigs which were innoculated with tissue fragments yielded negative postmortem findings. The microscopic examination revealed a very cellular, vascular growth suggestive sarcoma (Fig. 6, f). In view of the diagnosis, sections were submitted to two other local pathologists who confirmed the diagnosis. As the advisability of amputation had to be considered, slides and roentgenograms were submitted to the late Dr. Joseph C. Bloodgood, of Baltimore, who reported that he considered the microscopic appearance suggestive of angioma or angiosarcoma. He advised against amputation but urged continuation of the roentgen-ray treatments. Some months later, photomicrographs of the tumor tissue were submitted to Dr. James Ewing of New York City who expressed the opinion that it was a malignant neoplasm originating from vascular endothelium, but qualified this opinion by stating that it is hazardous to draw too sharp distinctions from photomicrographs.

Progress notes. Dr. Bloodgood's advice was followed, and the boy was given heavy doses of roentgen-ray over the foot and leg. He was discharged from the hospital on March 30, 1926. A roentgenogram taken at that time showed no increase in the

destructive process, and the edges of the cavity appeared smoother with evidence of bone condensation. He was seen at intervals for a year and a half, roentgenograms being taken frequently with no evidence of recurrence. He continued to have pain, however, and was unable to bear full weight on the affected leg.

The patient then disappeared from treatment and was not seen until 3 years later (1930) when he was readmitted to the hospital. He was walking with a crutch, complaining of severe pain in the right foot. He stated that he had not been able to bear weight on the affected leg since he was discharged. Examination revealed marked atrophy of the right lower extremity with shortening of 6 inches. There was a severe equinovalgus and cavus deformity of the foot with contracture of the plantar fascia. A roentgenogram showed that the original cavity of the calcaneus was completely healed (Fig. 6, b). An attempt was made to correct the deformity of the foot by means of a wedge osteotomy. After 2 or 3 months the cast was removed, and he was discharged from the hospital.

He returned in 1933 at which time he still complained of pain and inability to walk. Examination revealed that the deformity had recurred. The foot was especially tender in the midtarsal region. Roentgenograms revealed an area of destruction involving the midtarsal bones which had not been evident in the previous pictures (Fig. 6, c). In view of the new lesion and the marked disability in the leg due to pain, shortening, and deformity, amputation was performed through the middle third of the leg in September, 1933. He made an uneventful recovery and was fitted with a prosthesis 3 months later. He was last seen in November, 1935, at which time he was apparently in excellent health. Verbal reports since then indicate that he is well.

Pathological report of the amputated specimen. The foot was cut through the sagittal plane, the calcaneus and midtarsal bones being split. A dark, chocolate brown, circumscribed tumor consisting of soft, friable, very vascular tissue was found involving the navicular, cuboid, and second cuneiform bones. The calcaneus was small and atrophic, but there was no evidence of tumor tissue (Fig. 6, c). Microscopically the tumor was composed of many vascular spaces lined with endothelial cells. The true angiomatous character of the tumor was much more readily discernible than in the sections from the calcaneus made 7 years previously. The blood spaces were much larger, the tumor cells being less densely packed and apparently not as proliferative as in the previous sections. Connective tissue was less dense but more abundant. Red blood cells were seen in some of the vascular spaces. Granules of blood pigment were present. Endothelial proliferation and new blood vessel formation were a prominent part of the picture. In some areas the endothelial proliferation was marked, cells being so densely packed that obliteration of vascular spaces was noted (Fig. 6, g).

This case is of unusual interest not only because of its rarity in regard to type, location, and age, but also because of the rather striking changes that were observed over a period of 7 years before amputation was done. At first the tumor showed many signs of malignancy, and there was some difference of opinion among the pathologists on this point. The original sections showed such marked endothelial proliferation that the vascular spaces were almost obscured and the histological, as well as the roentgenographic, appearance strongly suggested sarcoma. As time passed, however, the primary lesion eventually was obliterated, as indicated by the roentgenograms and the pathological examination of the amputated foot. The marked shortening of the leg with atrophy probably should be attributed to the effect of the roentgen-ray therapy on the epiphyseal cartilage.

The final roentgenograms taken 7 years after the first operation revealed a surprising condition in the presence of a large destructive lesion in the midtarsal region, which had not been evident in the previous pictures. Pathological examination revealed an angiomatous tumor in this area which histologically resembled more nearly a benign capillary angioma than an angiosarcoma, although there were areas which still showed marked endothelial proliferation. Nevertheless, the structural differences between the original lesion in the calcaneus and those of the tumor in the midtarsal region were quite evident. The question arises whether the latter tumor was the result of direct invasion from the original lesion, or whether it developed from a second congenital focus, independent of the primary lesion. The serial roentgenograms and the gross appearance of this tumor suggest that the latter mode of origin was quite possible.

Because of its angioblastic tendency and its recurrence after apparent cure, this tumor is classified as an angiosarcoma of low grade malignancy. Its varied histogenesis demonstrates the difficulties involved in the identification and classification of angioblastic tumors.

CONCLUSIONS

A review of current opinions on the pathology of vascular tumors indicates that they are

mesenchymal tumors arising from congenital rests by a process of endothelial proliferation and differentiation into new blood vessels. They occur in both benign and malignant forms. They are true endotheliomas.

The typical benign angioma is a highly differentiated structure composed of fully developed blood vessels which grows slowly and with little evidence of cellular activity.

Malignant angiomas, on the other hand, are characterized by rapid growth, invasion of surrounding tissue, and sometimes metastasis. They consist of very cellular angioblastic tissue which in its histogenesis tends to revert to the original primitive mesenchymal structure, producing a varied histological picture differing greatly from the well differentiated benign forms. Often in these malignant forms the primitive mesenchymal structure will assume morphological characteristics resembling either connective tissue (sarcoma) or epithelial tissue (carcinoma), rendering their histological diagnosis extremely difficult. They all possess one feature in common, however, essential for diagnosis. There is always present an angioblastic tendency evidenced by endothelial proliferation and the formation of new blood vessels.

Tumors arising from blood vessels in bones are rare, but their inclusion in a special class of bone tumors is justified on the basis of certain distinctive pathological and clinical features which they possess. A clinical and pathological study of 27 angiomas of bone has been herein reported.

The benign forms possess certain roentgenographic and pathological features which are practically diagnostic. These features have been described in considerable detail.

The malignant forms, on the other hand, are most varied in their structure and growth and offer more difficult problems in diagnosis. It is suggested that on the basis of histogenesis the malignant angiomas of bone can be divided into two subdivisions, the angioendothelioma and the angiosarcoma. Angioendothelioma is an angioblastic tumor, but with an epithelium-like structure, difficult to distinguish from metastatic carcinoma. In agiosarcoma the vasoformative tendency is a more predominant feature, the new blood vessel being the unit of the tumor rather than the proliferating endothelial cell. Examples of both of these types of malignant angiomas are included in the series. These two groups vary greatly in their growth and malignant tendencies and they possess few characteristic roentgenographic or clinical features distinguishing them from other malignant tumors of bone. Diagnosis is based largely on their histological appearance. They are only moderately radiosensitive, and early diagnosis and radical surgical treatment are essential for cure.

SUMMARY

1. A pathological and clinical analysis of 27 cases of benign and malignant vascular tumors involving bone is reported.

2. A résumé of current opinions on the pathology of vascular tumors is included, special attention being directed to histogenesis and classification.

3. It is suggested that malignant angiomas of bone can be divided into angioendothelioma and angiosarcoma. The distinctive features of each are given.

4. Treatment of vascular tumors of bone is outlined, emphasizing the importance of early diagnosis and radical surgery in the malignant types.

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SUPPURATIVE JOINT DISEASE AND ITS RELATION TO PYOGENIC OSTEOMYELITIS

A Review of End-Results of 67 Involved Joints in 57 Patients; Modern Chemotherapeusis

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INTEREST in the outcome from major joint suppuration appears to have been stimulated by World War I, coincident with an awakening of interest in the long term outcome from injuries and disease incurred in that conflict. During that period, the revolutionary and heroic treatment of Willems was inaugurated only to fall into later disrepute among his civilian surgical successors. A rational treatment of the condition appears not to have been devised until the late Russell Hibbs contended that pus within a joint played the major rôle in destroying its cartilage. To lessen this potential damage, surgical drainage of the joint was deemed necessary to provide an avenue of escape for purulent materials. Phemister later demonstrated a tryptic ferment in the products of pyogenic suppuration and showed that a pyogenic exudate will dissolve cartilage *in vitro*. He was unable to demonstrate a similar ferment in tuberculous pus. This same author also established the fact that pressure in the presence of a pyogenic exudate accelerated the erosion of cartilage. Traction on a joint, which separates its articular surfaces, together with arthrotomy or other drainage, became the accepted and logical treatment. It is the only effective means of treating suppurating joints, but its exact application varies with the joint. This regimen led to preservation of motion in the largest percentage of cases, but it has been only in later years that end-results of a large number of cases have become available. The historical aspects of the changing surgical viewpoint concerning the therapy of suppurative joints will not be reviewed in this place because excellent historical summaries have preceded this paper. They will be found in the writings of Garrison, Bick, Inge and Liebolt, and Wilensky.

The exact differentiation between the causes of joint suppuration had to await the successful routine application of bacteriological methods to this disease. However, many years prior to these applications of bacteriology, Wisseman (17th century) was credited with differentiating the clinical features of suppurative joint disease from the "tumor albus" of tuberculous disease of the knee. However, this differentiation was not made with ease and certainty until Phemister pointed out the roentgen characters of suppurative joint disease as compared with those of tuberculous infection of the joints. In the former, destruction of the cartilage and then the "joint space" occurred first in the contacted or "weight bearing" portions of the joint, while tuberculous pannus destroyed the noncontacted portions of the articular cartilage by growing over the joint from the peripheral nonweight bearing portions. The surface spread of tuberculous tissue is inhibited by motion and contact. From a clinical point of view, the acuteness of suppurative joint disease usually prevents confusion with tuberculous joint involvement. In civilian life, the frank association of acute and chronic pyogenic osteomyelitis with the production of suppuration within the joints further aids in clinical diagnosis. The frequency of joint complications from suppurative joint disease has varied in the statistics of different authors. These are given in Table I. In general, there has apparently been a closer association of suppurating joints with pyogenic bone involvement in recent years. This apparent greater association of bone infection as a point of origin of

From the Section on Orthopedic and Traumatic Surgery, The Guthrie Clinic and the Robert Packer Hospital.

TABLE I.—DISTRIBUTION OF PYOGENIC ARTHRITIS BY JOINTS—ACCORDING TO VARIOUS AUTHORS

	Bisgard	Lewis (cited by Wilensky)	Wilensky	Blaisdell and Harmon
Hip	26.4%	21.1%	15.6%	34.3%
Knee	36%	41.1%	28.1%	38.8%
Ankle	22.6%		15.6%	6.0%
Shoulder	3.8%	16.4%	3.1%	10.0%
Elbow	1.9%	18.8%	15.6%	
Wrist	1.9%		3.1%	7.5%
Spine				
No. cases	53	85	32	67

joint suppuration is accounted for by the smaller incidence of penetrating injuries in civilian practice and by the greater frequency of roentgenographic study of bone and joint disorders.

From the historical aspect, recommendations for treatment have varied. Early surgical writers recommended simple incision of the joint "to evacuate the matter," noting that the joint finally became immobile as a result. During the period when amputation of the extremities was a popular surgical procedure, suppuration in the major joints was considered an indication for amputation. The modern tendency, except for the introduction of the Willems treatment, which is no longer generally practiced, has been toward conservatism. Roentgen visualization of the involved part has allowed the surgeon to direct his treatment intelligently toward discovery and concomitant treatment of bone suppuration. There have been no contributions of major importance since those of Phemister until the recent application of specific chemotherapy. Notwithstanding, the grade of treatment has steadily improved and with it the end-results. It should be brought out, though, that regardless of the diligence and persistence in surgical care, many cases will suffer ankylosis and loss of extremity length because of the extent of initial bone disease, a factor not under control of the surgeon in cases in which the infection has occurred by the blood stream.

We have found 57 patients with suppurative joints in the records of the Guthrie Clinic

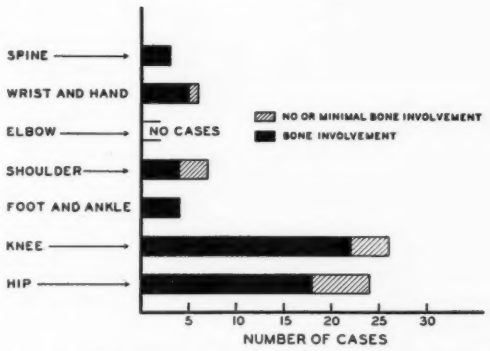


Fig. 1. Involvement of various joints by suppurative joint disease. Cross hatch areas, no or minimal bone involvement; black areas, bone involvement.

and the Robert Packer Hospital. While some of these patients presented multiple joint involvement, 67 separate joints were available for study. These cases represent all those seen in a period of 8 years, but our treatment, as described in a later section of this paper, was applied to only a few of them inasmuch as it has been evolved as a result of the relatively recent applications of chemotherapy.

In general, the application of chemotherapy, following prompt diagnosis and arthrotomy, probably would result in better general outcome than that presented by this whole group of cases (Table II). Figure 1 gives the distribution of cases according to joint involvement. During the same period of time, 488 cases of pyogenic osteomyelitis were seen in this institution. Those with joint involvement made up 11.7 per cent of the total. Males comprised 70.7 per cent of this latter number, a finding in agreement with the usual greater incidence of suppurative bone disease in this group. The age incidence was 0 to 10 years, 26.3 per cent; 11 to 20 years, 29.8 per cent; 21 to 30 years, 14.0 per cent; over 30 years, 23.0 per cent. The age incidence was unknown in 7.0 per cent of the cases. The purpose of this paper is to emphasize the need for early and prompt bacteriological diagnosis by joint aspiration and vigorous and meticulous therapy including the prolonged application of traction to the involved extremity and to describe the application of specific chemotherapy, both during the acute stage and as

TABLE II.—RELATIONSHIP TO BONE INVOLVEMENT AND DURATION

Name	Sex	Age at onset of joint disease	Age first seen for joint disease	Duration of active involvement	Joint involved	Previous osteomyelitis	Traumatic?	Results	Concomitant osteomyelitis	Status of joint when seen first
V. A.	M	11	11	79 days	L. knee	o	X	Cured	X	Acute
W. B.	M	7	8	8½ mos.	L. hip	X	X	Healed deformity	X	Healed deformity
L. B.	M	10–11?	11	?	L. hip; R. hip	X	o	Healed deformity	X	Healed deformity
C. B.	M	6?	18	6 yrs.	R. hip	X	o	Chronic	X	Chronic
B. B.	F	10	15	?	L. hip	?	?	Healed deformity	?	Healed deformity
H. B.	M	20	48	28	R. knee	X	X	Chronic	X	Chronic
E. C.	M	19	19	112 days	R. shoulder	o	o	Healed deformity	o	Healed deformity
M. C.	F	18m	18m	170 days	L. hip	o	o	Healed without deformity	X	Acute
A. C.	F	12	12	9 days	L. hip	o	o	Died	X	Acute
R. C.	M	9	9	85 days	L. knee	o	X	Chronic osteomyelitis	X	Acute
B. C.	M	64	64	180 days	R. knee	o	X	Improved	o	Chronic
F. I. C.	F	5½w	5½w	13 days	L. knee L. shoulder	o	o	Improved	X	Acute
T. C.	M	49	49	57 days	R. hip	o	o	Good	X	Acute
H. C.	M	23	23	412 days	L. hip	o	X	Died	X	Chronic
W. F.	F	17	17	116 days	L. hip	o	o	Improved	o	Acute
B. F.	F	15m	15m	48 days	R. wrist	X	o	Cured	X	Acute
H. F.	M	14	26	116 days	R. knee	X	o	Cured (amputated)	X	Chronic
C. G.	M	6	6	?	Hips	X	o	?	X	Chronic
A. G.	F	40	42	39 days	L. knee	X	o	Fusion	X	Chronic
H. G.	M	18	18	40 days	R. knee	o	X	Cured	o	Acute
R. G.	M	9	9	393 days	R. knee	o	X	Died	X	Acute
L. H.	F	10m	10m	29 days	L. knee	o	X	Cured	o	Acute
F. H.	M	28	28	29 days	L. hip	o	X	Ankylosed	X	Acute
R. H.	M	29	29	?	L. knee	o	o	Shortening with flexion deformity	X	?
S. J.	F	65	68	2½ yrs.	L. ankle	o	X	Unimproved	X	Chronic
R. J.	M	4	4	164 days	R. hip; L. knee	o	X	Cured	X	Acute
S. K.	M	18	18	118 days	L.wrist; R.hip	X	o	Cured	X	Acute
P. G.	F	?	35	?	L. hip	?	?	Good	?	Chronic
A. M.	M	?	20	?	R. knee	X	o	Died	X	Chronic
R. M.	M	?	9	?	R. knee; R. hip	X	o	Cured	X	Chronic
A. M.	F	66	66	103 days	L. hip	o	X	Died	o	Fractured
B. A. N.	F	41	41	38 days	L. ankle	X	X	Died	X	Chronic
J. P.	F	28	49	yrs.	L. knee	X	X	Fusion	X	Chronic
W. P.	M	14	14	52 days	R. hip	X	o	Healed	X	Acute
T. Q.	M	10	10	recurrent	L.knee;R.knee	o	X	?	X	Acute
J. R.	M	21	21	133 days	R. knee	o	o	Healed	o	Acute
H. M.	M	18	46	yrs.	R. hip	o	X	3 inches short	X	Healed
T. S.	M	14	14	yrs.	L.knee; R.knee	X	X	Fused	X	Acute
C. S.	M	19	19	69 days	R. shoulder	o	X	Ankylosis	o	Acute
H. S.	M	12	12	25 days	L. knee	X	o	Cured	X	Acute
N. S.	M	63	63	84 days	R. shoulder	X	o	Chronic sinus	X	Acute

TABLE II.—RELATIONSHIP TO BONE INVOLVEMENT AND DURATION—Continued

Name	Sex	Age at onset of joint disease	Age first seen for joint disease	Duration of active involvement	Joint involved	Previous osteomyelitis	Traumatic?	Results	Concomitant osteomyelitis	Status of joint when seen first
E. S.	M	12	12	few days	L. ankle	X	o	Cured	X	Acute
C. S.	M	4	4	12 days	L. knee	o	X	Cured	o	Acute
J. S.	F	54	54	89 days	R. knee R. ankle	o	o	Chronic osteomyelitis	X	Acute
E. S.	F	7	15	yrs.	R. hip	o	X	Chronic osteomyelitis	X	Subacute
F. S.	M	26	60	?	L. knee	X	o	Fused	X	Healed
G. W.	M	11d	11d	27 days	L. shoulder	o	o	Healed	X	Acute
A. W.	M	37	37	67 days	R. knee	X	o	Died	X	Acute
D. B.	M	31	37	6 yrs.	L. spine	o	X	Cured	X	Chronic
B. B.	M	41	41	127 days	L. knee	o	X	Stiff knee	X	Chronic osteomyelitis
M. B.	M	31	31	365 days	L. wrist L. shoulder	o	X	Ankylosis	X	Acute
C. H.	M	35	35	23 days	R. hand	o	X	Improved	o	Acute
H. M.	M	?	?	?	L. hip	X	o	Cured	X	Healed
R. W.	M	24	24	84 days	R. hand	o	X	Amputated	X	Acute
R. K.	M	25	25	64	T-12, L-1 R. shoulder	X	o	Improved	X	Acute
D. S.	F	15	15	yrs. chr.	R. hip	o	X	Chronic osteomyelitis	X	Acute
J. G.	M	18	18	10 days	Spine	X	o	Cured ankylosis	X	Acute

SUMMARY—57 cases
Died—7
Chronic or ankylosed or both, with draining sinuses, 25; improved (healed, occasional minor discomfort), 5; cured (included 2 cases cured by amputation), 20.

used to heal the wound. The employment of traction results in a greater percentage of movable joints in the end-results (see section on treatment).

DIAGNOSTIC CONSIDERATIONS

The patient with suppurating joint disease presents himself with a painful, swollen, and immobile joint, splinted by spasm of neighboring muscles. This situation is the sequel of either pre-existing neighboring bone disease or a penetrating local injury. Occasionally, the initial bone disease has long been quiescent and has had a recent reactivation by trauma. The usual accompanying symptoms and findings of acute or subacute infection are present: fever, a variable degree of "toxemia," prostration, and an increase in circulating polymorphonuclear neutrophilic leucocytes in the peripheral blood. The local findings should immediately direct the attention of the surgeon to the joint. The chief conditions to be considered in differential diagnosis are (a) acute rheumatic fever; (b) sympathetic sterile joint effusion produced by trauma or neighboring infection; (c) intermittent hydroarthrosis; (d) joint tuberculosis; (e) hemophilia; (f) traumatic hemarthrosis, which may accompany marginal fractures and "sprains"; (g) acute rheumatoid arthritis—in children, Still's disease; (h) acute bursitis; (i) periarticular cellulitis; (j) small fractures and sprains. (See Figure 2).

In the instance of the deep lying joints—hip, shoulder, intervertebral joints and temporomandibular joints—the local joint distention may be masked by pain and muscle spasm. The presence of pus within the joint can be confirmed only by aspiration, since periarticular suppuration will often closely simulate the findings of intra-articular involvement. Aspiration is further indicated at the earliest possible moment, in order to obtain material for smear and culture by the bacteriologist. From his report, specific chemotherapy is prescribed. Aspiration is the

first step in treatment since suppurative products should not be allowed to accumulate. In certain cases this is adequately prevented by one or more joint aspirations (see section on treatment).

The surgeon should not be content with positive findings in a single joint; all the joints and exposed and accessible bones should receive a meticulous physical examination since suppurative bone and joint disease is frequently multiple. The symptoms in a single joint may overshadow those in other joints and the unwary diagnostician may neglect or overlook an important part of the patient's disease. In our series, 9 patients, 15.8 per cent, presented multiple joint involvement.

The symptoms arising from the systemic phase of suppuration (septicemia) may also largely or completely mask the metastatic manifestations. In these instances, the most important consideration is the chemotherapeutic treatment of the general infection and the general care of the patient rather than local attention to the joint. Selection of the appropriate drug in these cases is essential. In addition, blood cultures should be made in every case of manifest joint disease as a control upon the adequacy of dosage of the sulfonamide series of drugs.

Roentgenograms should be made of the joint and neighboring bones when the patient is first seen. They will usually show no alterations, unless the patient has had previous neighboring bone disease. The earliest finding is narrowing of the joint space (Fig. 3), which is often not detectable unless a roentgenogram of the contralateral corresponding joint is available. This narrowing is not pathognomonic of acute joint disease as it may be produced by pre-existing chronic joint disease. In the latter instance, characteristic bone markings will usually give a clue to the nature of pre-existing bone disease; for example, sclerosis, osteophytes with or without bone destruction. If suppuration in the area is of recent origin, no osseous alterations can be expected prior to 7 to 14 days after onset since that is the time of appearance of demineralization due to acute bone suppuration. The osseous limits of suppuration may not be visualized by the roentgen-ray until 3 to 4 weeks after onset. The importance of these facts in relation to treatment will be brought out later. There is seldom any confusion in interpreting acute, progressive demineralization of the bones as visualized by roentgenograms taken at weekly or fortnightly intervals, for in no other condition does this process advance so rapidly. Small osseous foci which are responsible for initiating joint suppuration may not be visualized for several weeks (3–8). These smaller foci have no bearing on treatment and are of scientific interest only. See Figure 4 for representative cases of slight to moderate osteomyelitic involvement which has resulted in suppurative arthritis. In the instance of primary joint suppuration, especially if purulent products are not removed by aspiration or arthrotomy, solution of the cartilage promptly occurs and a roentgenogram of the joint will subsequently show erosion of bony articular cortex or sequestration of this structure and solution of the underlying cancellous bone (Fig. 5). There is usually no need for these latter changes to occur if aspiration and prompt, adequate treatment is executed.

TREATMENT

Opinion is now fairly well crystallized upon the measures to be followed in treating acute and chronic suppuration within the peripheral joints. The basis for the procedures to be described has already been discussed: the indications are to preserve motion, if possible, and to relieve pain and minimize joint damage by removing suppurative products and by traction. Chemotherapy aids in controlling suppuration and in sterilizing the blood stream when involved. Some variation in treatment is needed when extensive osteomyelitis of the long bones is present, as it may not then be possible to allow joint motion to remain when appropriate treatment is being given for the extensive bone infection. The management of chronic cases differs from those in the acute stage and will be discussed subsequently. The prompt application of the above measures resulting in a successful outcome in the acute case is illustrated by the following report of a case of acute suppurative arthritis of the knee following an infected

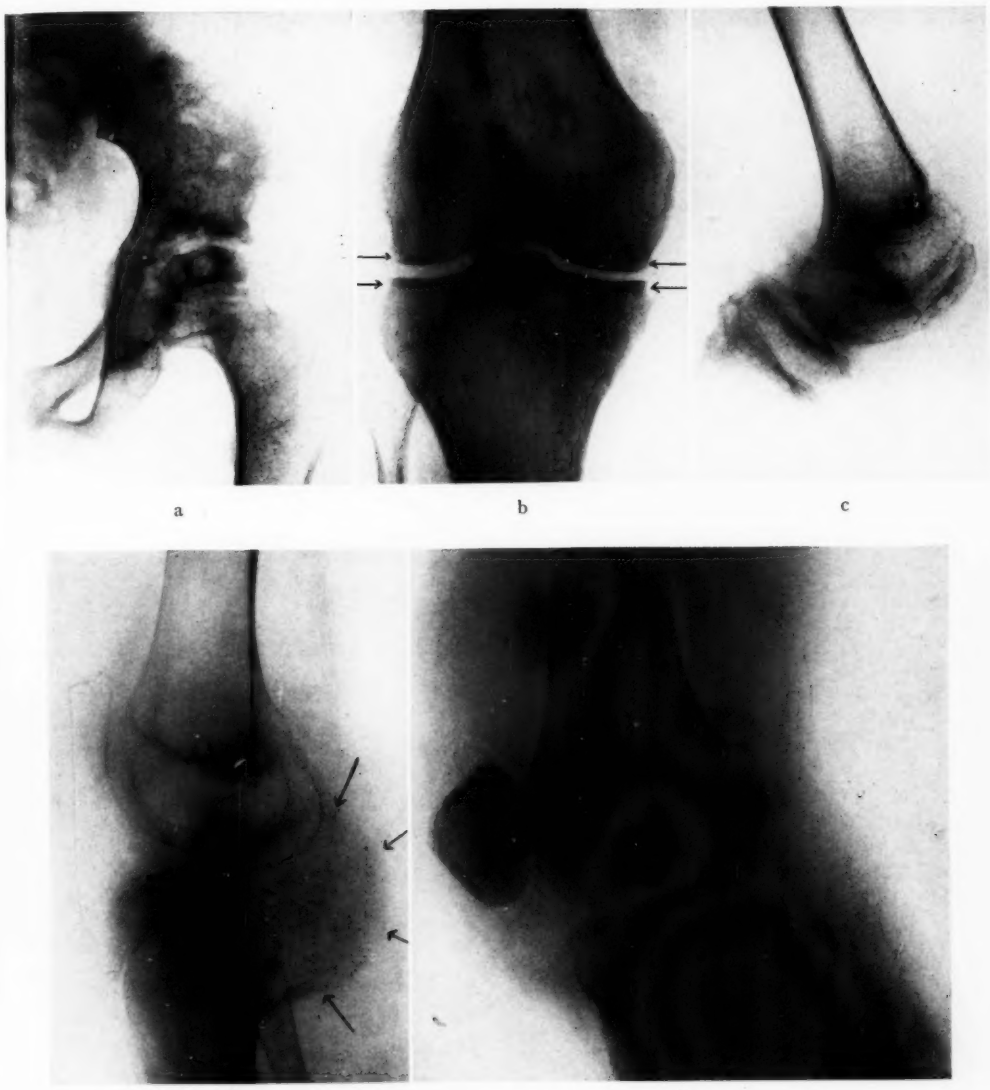
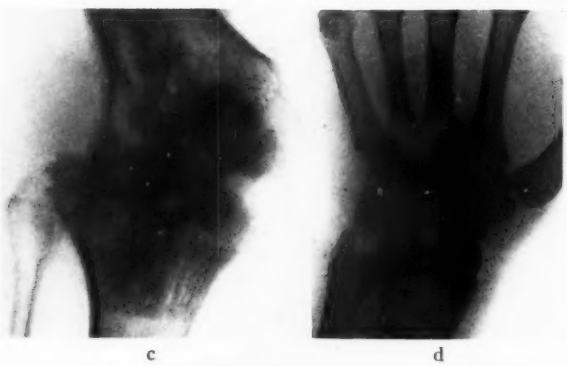


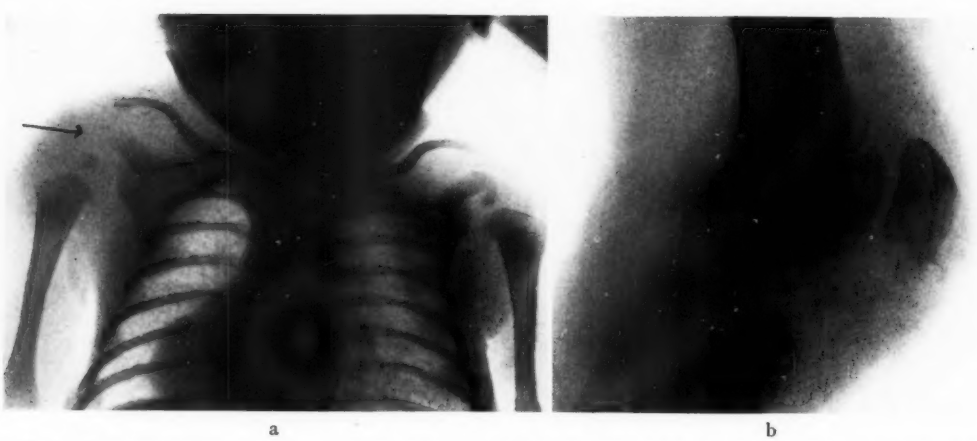
Fig. 2. Roentgenograms of 5 cases illustrating differential diagnosis from suppurative joint disease. a, Tuberculosis of the hip in a juvenile patient. Note destruction on both sides of the joint predominating in the nonweight bearing portions of the joint. b, Early tuberculosis of the knee in an adult. This case demonstrates the classical early findings in roentgenograms with marginal and intercondylar bone destruction (nonweight bearing portions of the joint). c, Hemophiliac "arthritis" showing bone atrophy, subchondral cysts, lamellation at the anterior and posterior portions of the distal femoral epiphysis and premature but symmetrical closure of epiphyseal lines. d, Chondrosarcoma of the upper tibia protruding posteriorly. Bone destruction and spotty calcification in the tumor establishes the roentgen diagnosis. e, Acute trauma to the knee without fracture followed by hemarthrosis. Occasionally this condition will be followed by infection when a penetrating wound is present.

a b¹ b²



c d

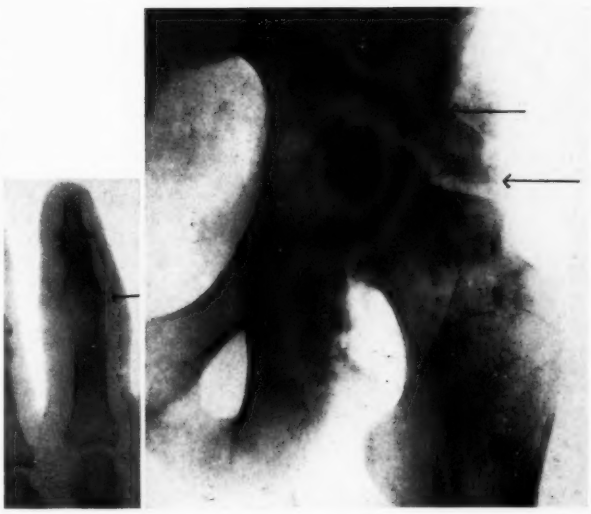
Fig. 3. Roentgenograms of suppurative arthritis involving 4 different joints in the same number of patients. a, Hip; b, shoulder; c, knee; d, wrist. Note that in all these instances, there is a certain amount of marginal bone demineralization adjacent and within the joint. Note also the joint sequestrum of the capital femoral epiphysis in, a, b¹ and b², are views taken before and after surgical removal of diseased bone adjacent to the glenoid.



a b

Fig. 4. Roentgenograms of small juxtarticular osseous suppurative focus which has broken into and caused joint infection. a, Tip of acromium in an infant which has infected shoulder joint. Compare soft tissue swelling of involved shoulder with uninvolved contralateral joint. b, Inferior portion of patella, ruptured into knee joint.

a b¹ b²



c d

Fig. 5. Roentgenograms illustrating surface erosion of bone and destruction of osseous articular cortex by suppuration. a, Hematogenous osteomyelitis of the ilium in a child of 3 years, causing suppurative arthritis of the hip in which the triradiate cartilage of junction of the pelvis has been destroyed by suppuration. b¹, Chronic suppurative arthritis of the tibioastragalar and the subastragalar joints in which the shadow of articular cortex on the inferior tibia and the superior and inferior astragalar surfaces has been destroyed. b², The same case showing direction taken by a radio-opaque medium injected into a posterior sinus. Osseous tuberculosis was ruled out in this case. c, Involvement of the proximal interphalangeal joint with destruction of the osseous articular cortex. d, Primary suppuration within the hip joint which has resulted in sequestration of the upper fourth of the femoral head. Note loss of joint space, surface erosion of the osseous cortex over the remainder of the femoral head and subarticular demineralization in the ilium. This latter was due to hyperemia neighboring a suppurative focus as demonstrated at necropsy.

puncture wound, uncomplicated by osteomyelitis.

Case 1. C. S., aged 4 years, was admitted to the Guthrie Clinic and the Robert Packer Hospital 8 days after a puncture wound occurred on the left foot. The wound became infected and the infection ascended into the leg by the lymph channels. A hypodermic needle was broken off near the patella by a local physician who first treated the patient. This latter site soon became infected, the knee swelled, and walking was very painful for 2 days just prior to admission. On admission, the left knee was warm to touch, patellar ballotment associated with pain was present, and the patient was able to flex the knee but 15 degrees because of exquisite pain. Roentgenograms upon admission showed the increased volume of soft tissues and the foreign body (needle) but were otherwise negative. Laboratory studies were negative except for a leucocytosis—13,000—and an increased sedimentation rate—27 millimeters in 1 hour. The patient was placed in bed on a Bradford frame, the left knee was extended by adhesive tape traction applied to the

TABLE III.—BLOOD AND KNEE JOINT CONCENTRATIONS OF SULFATHIAZOLE

Patient	Total (gm.) by mouth	Time after starting initial dose (days)	Blood conc. (mgm./100 c.c.)	Knee conc. (mgm./100 c.c.)	Pct. knee /blood
D. H.	9	1*	4.1*	2.7	66
R. W.	64	10	5.2	R.3.6 L.3.3.	70 63
	70	11	6.3	R.4.4 L.4.0	69 64
C. R.	36	6	3.8	3.0	78
E. M.	8	1	5.3	4.6	87
F. B.	15	2	5.0	4.5	90
G. P.	14	2	6.1	4.6	75

*4 gms. of sulfathiazole placed in the wound when débridement and suture of compound fracture of patella was performed.

leg. Aspiration of the knee joint obtained 50 cubic centimeters of purulent fluid from which the Staphylococcus aureus was cultured. Sulfathiazole was given the patient in 0.5 gram doses every 4 hours. In the next 3 days the temperature rose to 102.6 degrees F., and swelling of the knee returned. Four days after admission a parapatellar arthrotomy was performed, and the small foreign body was removed. Synovia was stitched to the skin in each incision and two soft rubber drains were placed through the incision, with care that neither touched cartilage. Traction and sulfathiazole were continued. On the second postoperative day, the temperature did not exceed 100.2 degrees F. and the patient appeared to have improved. He was kept recumbent in traction for 21 more days. The rubber drains were allowed to remain in place for only 5 days until satisfactorily large bilateral parapatellar sinuses were established. He was discharged from the hospital, draining but little on the twenty-third postoperative day. Three days after discharge from the hospital, all drainage ceased and the sinuses fully epithelialized during the following week. Six weeks after operation, almost a normal range of motion was present, and the patient had no swelling or pain in the knee. On a follow-up visit 7 months later the patient presented a normal appearing knee where there was a complete range of motion. Check-up roentgenograms at this time and previously failed to show any osseous foci of infection.

In this acute uncomplicated case, prompt arthrotomy, aided by traction throughout the period of recumbency, resulted in a successful outcome. Previous aspiration alone did not check the accumulation of suppurative products although in 3 cases in our series repeated aspiration alone sufficed to control the infection. Sulfathiazole was used to control the hemolytic Staphylococcus aureus infection. In later cases healing of the sinuses has been accelerated by the use of this drug and in some instances sulfadiazine, used in a powder atomizer. This general procedure is probably applicable to the greater majority of cases of suppurative arthritis occurring in the lower extremity. Occasionally, especially associated with seropurulent exudates due to infection with the α-hemolytic streptococcus, aspiration alone will relieve joint distention.

When massive acute osteomyelitis of the long bones complicates or causes joint suppuration, it is impossible to apply effective traction unless the localization of bone infection is in a site which will not interfere with its maintenance. These situations are not encountered with the frequency of uncomplicated joint suppuration and joint suppuration associated with minimal or moderate foci of osteomyelitis. The indication for cast treatment in preference to traction is the presence of pathological fracture or in the prevention of this condition. The following case of acute recrudescence of chronic osteomyelitis of the right femur with subsequent involvement of the right knee joint, is illustrative.

CASE 2. H. F., male, aged 26 years, was admitted to the Guthrie Clinic and Robert Packer Hospital, with a history of chronic osteomyelitis of the distal right femur of 12 years' duration. The past treatment included several surgical attacks and one postoperative course with maggots. He had been asymptomatic until 4 months prior to admission when he had experienced an acute local spread of the infection. Treatment had been delayed until both femoral condyles were involved by direct extension. Even at that time, involvement of the joint was not recognized elsewhere. He had had continued pain on active and passive motion due to joint involvement, even though the femoral osteomyelitis was adequately drained. Roentgen study showed diminution of the right knee joint space and painful patellar ballotment was present. Aspiration of the knee joint controlled his pain only partially and it was not until a long leg plaster was applied that he was almost pain free. The roentgen demonstration of the extent of osteomyelitis in the distal femur was a further indication for use of plaster since pathological fracture was feared.

Results that may be obtained in the future in treating these disorders may be expected to be better than the outcome in this series of cases inasmuch as the majority of these were treated before the advent of the use of the

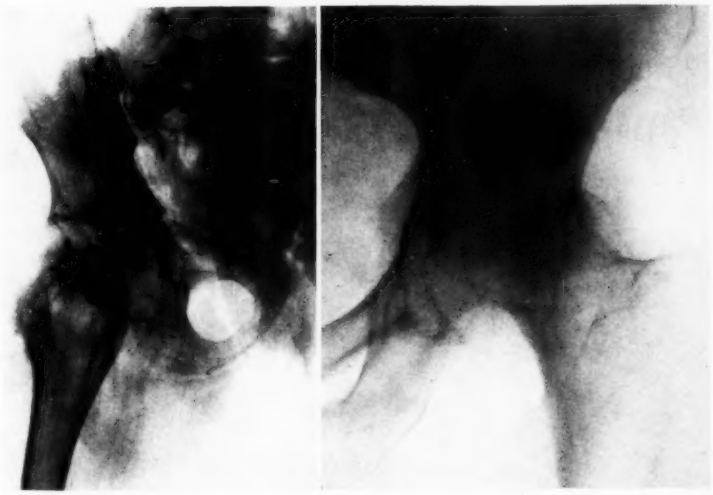


Fig. 6. Cases demonstrating contraindications to radical surgical treatment. a, left, Roentgenograms of pelvis of a child, age 10, 4 months after onset of acute suppurative arthritis of the hip and 3 months after the sequestrated femoral head was removed from the draining arthrotomy wound. During this time, the patient had been in a plaster hip spica. The roentgenogram shows a bone abscess in the proximal femur with numerous small sequestra adjacent to it. b, Roentgenogram of a chronic hip joint disorder of 3 years' standing, in an adult. This was proved by biopsy and culture to be a pyogenic joint. Operative fusion was contraindicated by the supra-acetabular osseous abscess.

sulfonamide group of drugs. These drugs are excreted from the blood stream into the joint in the presence of fluid exudate within these structures.

Table III summarizes cases in which the concentration of sulfathiazole in joints was determined in the presence of known blood levels of this drug. We are not cognizant of any similar observations upon record in the literature. These observations show that average concentrations of sulfathiazole in the knee joint in instances of sterile effusion are about two-thirds that of the blood concentration. Although no direct observations were made on the concentration of this drug in the instances of suppurating joints, it is likely the same or greater. At present, it is believed that there are no definite critical levels for the action of the drug, but it is desired that the blood concentration be kept between 3 and 8 milligrams per 100 cubic centimeters. To be effective in joints, however, the blood level should be kept at an adequate level which will usually result from a 4 gram initial dose followed by 4 daily doses of 1 to 1.5 grams each in adults. Sulfathiazole or sulfadiazine will be the drugs to be used in most instances inasmuch as most suppurative joint infections are produced by the staphylococcus. It should again be emphasized that the causative bacterial organism should be determined at the earliest possible moment in order to utilize chemotherapy most advantageously.

All gradations of severity of pyogenic joint infection are encountered. The chronic types with insidious onset are rare. Their symptoms and findings are the same as those of any chronic joint disorder except pain is likely to be severe and constant. Fever may or may not be an accompaniment. A certain number of these cases are confused with tuberculous joint involvement, as the roentgen picture is likely not to be characteristic of either. Aspiration with or without joint irrigation is the only means of diagnosis. Bacterial cultures of joint contents and frozen sections of synovia establish the diagnosis when arthrotomy has been performed under the mistaken diagnosis

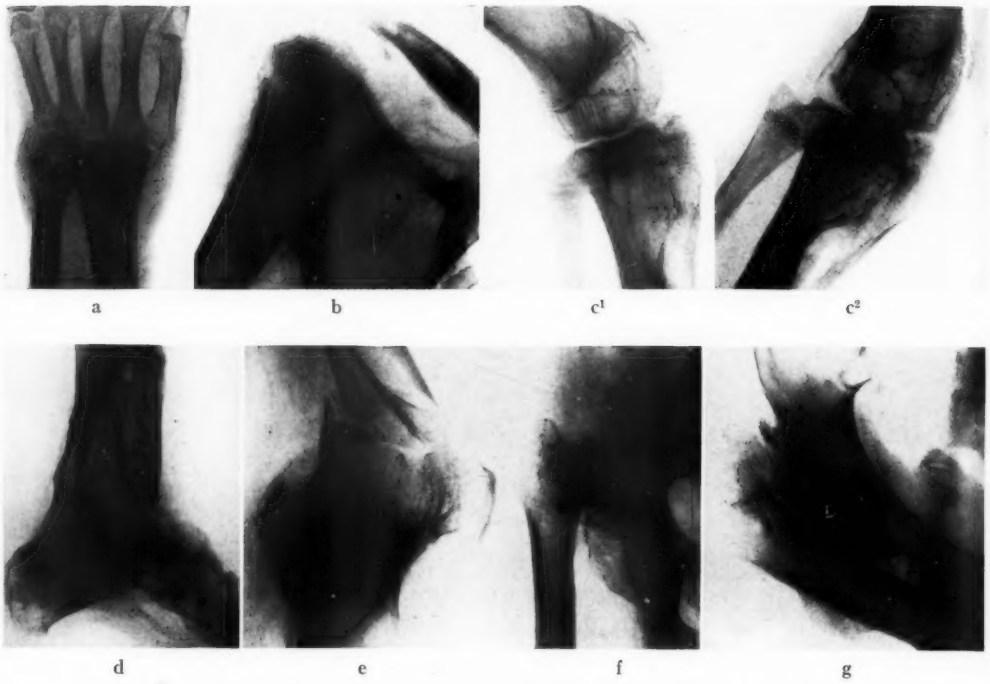


Fig. 7. Roentgenograms of some terminal and advanced deformities produced by suppurative arthritis (and neighboring osteomyelitis in some instances). a, End-result of wrist involvement. The proximal carpal remnants are fused to the radius. b, End-result of shoulder involvement of the same patient as in, a. Note the ossification in the capsule superiorly and advanced destruction of the glenoid. c^1 and c^2, Flexion deformity of the knee resulting from suppuration within that joint. These 2 films were taken 2 years apart. Note the improvement with passive stretching and weight bearing. d, End-result from panarthritis of the ankle joint in which all the joints about the astragalus have been destroyed by suppuration resulting in osseous ankylosis of all bones neighboring upon the astragalus. e, Roentgenogram of knee in an adult in which slight motion had been preserved following suppuration. Just before this plate was taken, the patient had suffered a supracondylar fracture. f, End-result of suppuration within the hip which had destroyed the femoral head, a portion of the neck and resulted in pathological dislocation. g, End-result of suppuration within the hip resulting in bone loss and a severe flexion-adduction deformity.

of tuberculosis of the joint. The infection may occasionally be sufficiently low in its virulence that bone grafts will survive when the unwary surgeon has performed an arthrodesis uncontrolled by synovial biopsy. Indications are that an increasing number of primary operations can be performed on chronic suppurating joints without the danger of sinuses developing when the sulfonamide drugs are used locally and by mouth following the operation.

The stationary case who presents himself with deformity is usually a problem involving the restoration of the weight bearing axis of the body. If the history has been that of an acute disease with rapid ankylosis with or without drainage of the joint, the diagnosis was almost certainly that of suppurative joint disease. Before performing osteotomies for the restoration of the weight bearing axis, roentgenograms should be scrupulously inspected for the presence of small sequestra or bone abscesses (Fig. 6). In the presence of these, operation should not be undertaken and should be deferred until neither are present, which may mean a period of years. There are, at present, indications that the restrictions in operating upon bone formerly the seat of infection can be relaxed when local and systemic chemotherapy (sulfathiazole or sulfadiazine or both) is utilized. However, the

a b

Fig. 8. Two patients with prepatellar bursitis. The patient with circumscribed bursitis in, a, would less likely be confused with suppuration within the joint than the patient in, b.

a b

Fig. 9. Two patients with residual deformity from suppurative arthritis. a, Patient 6 months after onset of suppuration in the glenoid face of the scapula. Note the loss of normal contour in the left shoulder and the drop in position of the muscle belly of the biceps due to rupture or detachment of the origin of the tendinous long head. b, Patient 4 years after suppuration in the left knee. Note flexion deformity of 30 degrees. He had only 10 degrees of motion in the knee at this time. Same patient as shown in roentgenograms, Figures 7c[1] and 7c[2].

limitations associated with this new auxiliary are not as yet defined and are still under clinical investigation. The factors involved in prognosis will be presented following the results in our own series of cases. Table II gives these in summary.

A review of the deformities produced by joint and adjacent bone suppuration in this series demonstrates some advanced and appalling skeletal derangements. In the acute cases, deformity was prevented by fixation in the positions of maximum function. Table II

reveals that many cases did not come under care until long periods after the acute onset. These patients, for the most part, presented deformities which under proper supervision could have been minimized or prevented entirely. Certain of these cases are illustrated in Figure 7. It is not within the scope of this paper to discuss the surgical treatment of deformities produced by suppuration within and near the joints as such a discussion would cover much of the field of reconstructive surgery.

SUMMARY AND CONCLUSIONS

1. The rationale of the treatment of acute joint suppuration by extension and arthrotomy is reviewed.

2. The outcome of 67 involved joints from 57 patients is tabulated and summarized. It is pointed out that these are poorer results than would be obtained under modern treatment with chemotherapeutic aid, since the latter tends to minimize suppuration in the acute stage and to allow elective and reconstructive operations to be performed in cases in which secondary operations were contraindicated.

3. Frequency of joint involvement by suppuration is in the following order: hip, knee, ankle, shoulder, elbow, and wrist.

4. The necessity of early diagnosis by joint aspiration and bacterial culture and smear is shown, since upon the results from bacterial culture and smear the proper chemotherapeutic agent is selected. When this information is lacking during the first few hours, the chemical agents that are active against the hemolytic Staphylococcus aureus (sulfathiazole or sulfadiazine) are to be used presumptively and change, if any, made as the result of the bacteriological findings. In children who have acute joint complications following upper respiratory and middle ear infections, sulfanilamide (α-hemolytic streptococci) is to be used presumptively.

5. Comparative joint and blood concentration of sulfathiazole are presented, as determined in 6 cases.

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SUPPLEMENTARY AND SYNERGISTIC ACTION OF STIMULATING DRUGS ON THE MOTILITY OF THE HUMAN COLON

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THE most uniform criticism of the drugs used to stimulate the motility of the human colon is their relative ineffectiveness in doses unaccompanied by undesirable side reactions such as nausea, vomiting, salivation, headache, and cardiovascular changes.

This investigation was undertaken with the idea that a combination of drugs might be found the dose of each of which would not cause side reactions, but in combination would effectively stimulate the colon. For example, Kerr Cross found that physostigmine and pituitrin in combination had a more powerful effect on the motility of the human appendix than either drug alone, and that the use of the two drugs in combination in the treatment of postoperative distention was more effective than either drug alone.

LITERATURE

Brief reference is made to some of the more recent studies regarding the action of the drugs to be used.

Pituitrin. A review of the literature reveals a rather wide difference of opinion in regard to the effect of pituitrin on the colon. Ochsner, Gage, and Cutting, basing their views principally on their review of the literature and observations on the dog, believe pituitrin to be ineffective. Frazier, basing his views principally on a review of the literature and on observations in man, believes that the drug is valuable in the management of adynamic ileus. He recommends that from 0.5 to 1 cubic centimeter of pitressin be given every 4 hours. According to our interpretation of the literature, pituitrin usually inhibits colon motility in the dog and usually stimulates colon motility in man. Our own experimental results confirm this interpretation.

Physostigmine. The literature clearly demonstrates that this drug stimulates the motility of the canine (13, 21, 24, 29) and human (6, 9, 10, 11, 23, 24) colon. Sometimes, however, effective doses produce undesirable side reactions.

Prostigmine. The use of this drug for the prevention and management of postoperative distention has been reported upon favorably by a number of authors (7, 8, 16, 17, 20, 31). Carmichael et al. observed the action of prostigmine in 41 patients. They showed that prostigmine methylsulphate in 0.5 milligram doses produces in normal subjects active movements of the colon, but there was no evidence that colon contents were moved. X-ray and barium studies revealed that considerable variation occurred in the response of different individuals to the drug. However, in the doses used, there were no side reactions and the drug was of value in gaseous distention if accompanied by an enema. The authors suggest that prostigmine followed by pituitrin and then an enema is an effective measure for stimulating peristalsis in postoperative distention. Levis and Axelman administered prostigmine methylsulphate (1 c.c. 1:4000 or 0.25 mgm.) as a prophylactic measure against ileus, at the time of operation and every 4 or 6 hours thereafter for 24 to 48 hours. The last injection was followed by a soapsuds enema. Prostigmine was found to be better than pituitrin. No side reactions as with eserine (physostigmine) were noted.

Ergotamine. Ergotamine in large doses apparently acts directly on the receptor mecha-

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TABLE I.—QUANTITATIVE DATA PERTAINING TO PROPULSIVE AND TOTAL MOTILITY IN THE COLON OF 4 DOGS AFTER INJECTION OF PITUITRIN, PHYSOSTIGMINE, AND PROSTIGMINE

No. of experiments	Control and drug experiments	Total motility			Propulsive motility		
		50 minute periods			50 minute periods		
		1	2	3	1	2	3
40	Controls (4 dogs)	57	62	54	13.0	11.6	9.2
6	1 unit pituitrin	21.5	29.3	34.8	4.4	5.6	6.5
6	2 units pituitrin	20.5	26.4	29.8	3.2	2.1	3.2
27	5 units pituitrin	10.5	8.6	15.9	0.7	0.6	1.4
16	0.5 mgm. physostigmine	66	69	71.0	19.4	22.1	16.2
16	1 mgm. physostigmine	69.5	72.0	73.4	29.8	26.1	24.3
8	1 c.c. 1:4000 prostigmine	63	67	68.1	16.5	18.2	17.2
8	1 c.c. 1:2000 prostigmine	68	76	72	25.4	26.5	24.3
8	2 c.c. 1:2000 prostigmine	74	78.9	83.4	27.3	29.5	29.8

Total motility = time in per cent that the colon is active per 50 minute period of experimental time. Propulsive motility = calculated as a per cent of total motility.

nism of muscle cells so as to prevent the cells from responding to the substance (sympathin) liberated by sympathetic or adrenergic nerve endings. In small or moderate doses the drug stimulates smooth muscle to contract, for example, the uterus and arterioles. Such doses are employed clinically. On this basis it was assumed that small doses of the drug might augment the activity of other stimulating drugs on the colon.

The effect of ergotamine on the motility of the intact gastrointestinal tract of man has received little attention. In doses of 1 or 2 milligrams given subcutaneously it sometimes causes nausea and vomiting (15). It delays gastric evacuation (32). Only one report (19) indicates that it may be of benefit in the management of postoperative distention.

METHODS AND PROCEDURE

Preliminary experiments were performed on dogs with an appendicostomy for the purpose of studying some of the drugs which were to be used on man. In the dog, considerable evidence is available regarding the effect of some of the drugs on *nonpropulsive* motility but none is available with direct evidence regarding their effect on *propulsive* motility. These are the two functional types of motility found in the alimentary tract.

Experiments on the dog. Four trained dogs with appendicostomy and weighing from 19 to 36 kilograms were used. The basal colonic motor activity of each was well known as a result of previous experimentation. The colon motility was recorded by the tandem balloon technique of Templeton and Lawson. One system of two balloons was placed in the proximal colon by way of the appendicostomy. A second two balloon system, recording motility from the distal colon, was inserted through the anus to such a distance that the most caudal balloon was located approximately 6 centimeters oral to the internal anal sphincter. The balloons were connected to individual water manometers by way of T-tubes and inflated according to a standard procedure (4). Since the position of the balloons is fixed, the tandem balloon method does not differentiate between propulsive and nonpropulsive motility. To differentiate such motility the propulsive force technique (4) was used. All drugs were injected intramuscularly.

Experiments on human subjects. Four ambulatory adult males with colostomy were studied by means of the balloon technique. These patients had the lower sigmoid and rectum resected from 6 to 18 months previously for carcinoma of the rectum. They were in excellent condition with no signs of metastases. The descending colon had been brought to the surface as a fistula. The subjects were under experimental observation morning and afternoon for at least 150 minutes at each session. *The colon was lavaged once a day (before breakfast) and usually no material was evacuated until the next morning when lavage was again performed.* During the day only slight leakage through the colostomy, and normally (for them) no gastrocolic reflex which led to expulsion of material occurred.

A one or two balloon system was introduced through the fistula to such a distance that the proximal portion of the descending colon was always studied. Our observations have been made chiefly from the region near the splenic flexure. After they were inserted, the balloons were inflated according to a standard procedure (4).

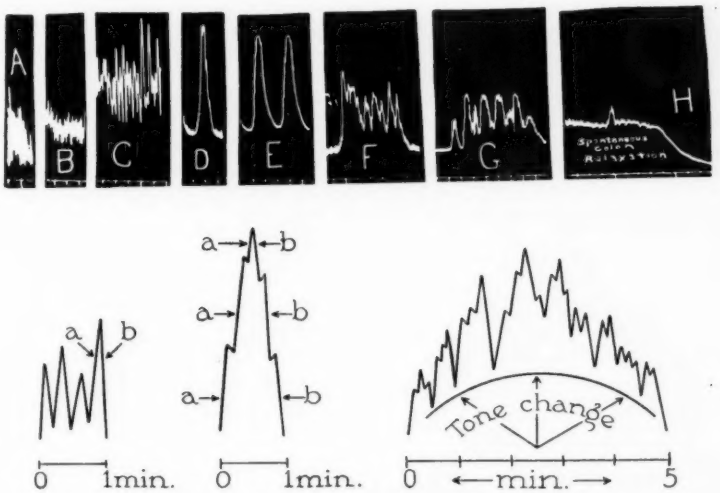

Fig. 1. A to H, Excerpts of tracings from the colon of *man:* A, B, C, type I contractions at various tonus levels; D, E, type II contractions; F, G, type III contractions; H, spontaneous relaxation of a balloon containing segment.

The types of contractions are diagrammatically represented showing the manner in which complex contraction patterns are built up from more simple contractions.

RESULTS

The normal or control motility. Functional types of motility. Two functional types of motility occur in the alimentary tract, one is *nonpropulsive* and the other *propulsive* in nature (28). Since drugs may affect these two types differently we have studied the effect of the drugs on each type.

Types of contractions in the human colon. Templeton and Lawson described three different types of contractions in the colon of the dog. We have found and reported the same types of contractions in the human colon (1) and have correlated the three types with propulsion of contents. Similar observations have again been made in this work and will be briefly reported at this time. The types of contractions as obtained by the balloon method are illustrated in Figure 1.

Type I contractions of various amplitudes, at a rate of 3 to 8 per minute occur on either high or low tone, usually on low tone. They are nonpropulsive. Type II contractions constitute the most frequent type of motility observed. They are propulsive only when they are of large amplitude and co-ordinated with the activity of adjacent colon segments. A low amplitude type II wave may be propulsive if the contents are liquid. Type III contractions consist of type II movements of variable amplitude superimposed on definite tonus waves. The type III wave is a change in tonus upon which are superimposed type II contractions which may be propulsive.

The quantity and functional quality of colon motility. Seventy control periods of at least 150 minutes in duration were obtained from the 4 human subjects. Forty similar control periods were conducted on the 4 dogs. Individual variations were noted, the expulsion of colon contents was recorded as well as the nonpropulsive and propulsive motility. The tracings were analyzed by adding the periods of time during which the colon was active; this gave the "total motility." The same was done for the "propulsive motility."

Referring to Table II, under the section "Experiments 2 hours after the last meal," it is to be noted that the colon of the 4 human subjects was active 53 per cent of the 50 minute period or it was active on the average 26 out of the 50 minutes of experimental time. Thirteen per cent of the activity was propulsive in type, or the colon manifested pro-

pulsive motility during 6.5 minutes of the 26 minutes. When the average is taken for the 70 periods of 150 minutes each on the 4 human subjects, it is seen that motility is present 80 minutes or about 50 per cent of the time and the propulsive motility constitutes about 10 per cent of the total. In individual experiments there is sometimes considerable deviation from this average ratio. However, the averages are significant because the most important analysis which can be made of the effects of drug administration on the colon is the extent to which each drug or drug combination affects the ratio of total motility to propulsive motility which normally is about 10:1. Of course, the quantity and quality of motility is subject to variation in the same and different human and canine subjects. During the course of an experimental period sudden changes in tonus and motility may occur which cannot be predicted. This emphasizes the necessity of obtaining numerous control studies when drug effects are to be evaluated. The averages of a number of tests minimize the error due to such spontaneous changes. In the human colon, periods of quiescence in a given segment may endure for as long as 60 minutes. On the other hand, periods of activity 180 minutes long have been observed in a segment of distal colon. Further, the activity of one segment is not an index of the type or the presence or absence of activity in a segment 3 to 4 inches proximal or distal. As in the dog, at times the motility of two adjacent segments appears to be integrated or co-ordinated, at other periods incoordinated.

The averages for the *40 control periods* on the 4 dogs (Table I) and are similar to those for the human (Table II). The action of the drugs on the dog's colon will be presented first.

The action of pituitrin. Dog. In 27 experiments of 150 minutes duration (Table I) surgical pituitrin injected intravenously at a rate of 0.1 cubic centimeter per 10 seconds for 5 units or intramuscularly in 5 unit doses (0.15 to 0.25 units per kgm.) invariably inhibited motility almost immediately and often definitely decreased the tonus. This effect lasted for from 30 minutes to several hours. In 20 of the experiments (intramuscular injection) depression of the motility took place in 5 to 10 minutes regardless of whether the drug was injected at a time when the colon was showing strong spontaneous motility or was in a state of quiescence. The distal colon was more profoundly depressed than the proximal, often remaining quiet for an hour after the motility in the proximal colon had returned to normal. In 2 instances it was observed that at least one balloon containing segment in the proximal colon was active whereas the remaining balloon containing segments in the proximal and distal colon were quiet.

In 12 experiments (Table I) smaller doses of pituitrin ranging from 1 to 2 units also inhibited motility but for a shorter time. Larger doses of pituitrin (10 to 15 units) sometimes had a side effect causing apprehension on the part of the animals, but the effect on the colon was the same. At no time was any stimulation of the colon motility in the unanesthetized dog seen after doses of pituitrin ranging from 1 to 15 units were injected. As one would expect, administration of pituitrin caused inhibition of balloon bolus propulsion and decreased propulsive force measurements when those techniques were employed (Table I). The results on the human colon were quite opposite (*vide infra*).

Physostigmine sulphate. Dog. By trial it was determined with the 4 balloon tandem technique that 1 milligram (0.015 to 0.025 mgm. per kilogram) of physostigmine given intramuscularly to 4 dogs was effective in producing propulsive motility. Two milligrams was too powerful, causing repeated defecation in all dogs, while 0.5 milligram stimulated the colon in only 12 or 16 experiments. One milligram in 14 experiments gave no untoward side effects, and the tandem balloon system showed that the whole colon participated in the reaction. However, tonus was increased and maintained at a high level in only 3 instances. Most frequently, rapid tone changes appeared in the form of propulsive type II contractions which were propagated distally from the proximal to the distal colon.

Eight experiments conducted on 4 dogs using the balloon bolus technique (3, 5) showed that the bolus moved rapidly from proximal

TABLE II.—QUANTITATIVE DATA PERTAINING TO PROPULSIVE AND NONPROPULSIVE MOTILITY IN THE HUMAN COLON AFTER DRUG ADMINISTRATION

No. of experiments	Control and drug experiments	Experiments 2 hrs. after last meal						Experiments 30 min. after last meal					
		Total motility			Propulsive motility			Total motility			Propulsive motility		
		50 min. periods			50 min. periods			50 min. periods			50 min. periods		
		1	2	3	1	2	3	1	2	3	1	2	3
70	Control 4 subjects	53	57	50	13	10.5	7.5	71	70	72	11.0	9.5	9.5
31*	Pituitrin (surg.) 1.25 units	42	56	51	48	9	6.3	58	65	67.5	42	10.5	10.2
20	Physostigmine 1 mgm.	59	68	70	16	18	21.6	83	87	86.5	17	18.4	17.3
22	Pituitrin (1.25 units) and physostigmine (1 mgm.)	62	71	71	46	15	24	63	74	78	44	20.5	21
30†	Prostigmine methylsulphate (0.5 mgm.)	69	75	83.5	19	22	23	80	82	83.2	20	24.4	34.4
16	Prostigmine bromide, tablets (15 mgm.)	49	59	64	9.0	10.2	14.6	68	64.5	76.4	12.4	13.4	14.5
16	Pituitrin (1.25 units) and prostigmine (0.25 mgm.)	64	72	76	43	24	19	71	76.4	77.6	39	26	33
12‡	Gynergen (ergotamine tartrate) (0.25 mgm.)	46	52	48.5	11	10.1	9.6	66	66.8	67.4	12	14	8.6
6	Gynergen (ergotamine tartrate tablet, 1 mgm.)	49	53	55	10.5	9.6	11.0	65	71.4	74	10.8	9.8	11
24	Ergotamine tartrate 0.25 mgm. and prostigmine 0.25 mgm.	71	75	74	24	27.5	24.3	74	77	74	29.6	27	29
8	Ergotamine tartrate tablet 1 mgm. and prostigmine bromide tablet 15 mgm.	56	57.4	58.4	14.1	12.1	13.8	68	67.6	71.4	12.3	13.1	13.8
12	Ergotamine tartrate 0.25 mgm. and prostigmine 0.25 mgm. and pituitrin 1.25 units	53	78	84	39	23	21	59	65.1	71.8	44	26	23

Total motility—time in per cent that the colon is active per 50 minute period of experimental time.
Propulsive motility—calculated as a per cent of total motility.
*Pituitrin—Surgical pituitrin (Parke, Davis and Co.).
†Prostigmine—Hoffmann-La Roche, Inc.
‡Gynergen—Ergotamine tartrate (Sandoz Chemical Works, Inc.).

colon to distal colon after administration of 1 milligram of physostigmine. Single, integrated type II contractions were capable of moving the bolus 10 to 15 centimeters in a few seconds. In only 1 case did a wave initially propel the bolus orally (reversed movement) for about 4 centimeters after which a second wave shifted it distally. Eight additional experiments conducted upon the 4 dogs with the propulsive force measuring apparatus (4) showed that the colon motility following the injection of 1 milligram physostigmine intramuscularly was highly propulsive. Tracings were obtained in which the individual type II contractions registered a propulsive force equivalent to 120 grams. Such waves of propulsion were recorded for 1 to 2 hours after the initial reaction of the colon to the physostigmine occurred from 15 to 25 minutes after intramuscular injection, and endured for several hours (Table I).

Prostigmine methylsulphate. Dog. Eighteen experiments conducted on 4 dogs with the use of the tandem balloon technique and the techniques used to measure propulsive motility revealed that prostigmine in doses of 1 cubic centimeter of a 1:4000 solution (0.25 mgm.) gave about the same results as 0.5 milligram of physostigmine. Doses of 1 cubic centimeter of a 1:2000 solution (0.5 mgm.) were much more effective and were equivalent in action to 1 milligram physostigmine. The propulsive waves were co-ordinated so that they were propagated to adjacent distal segments of the colon. No side effects other than increased salivation were noted with even 2 cubic centimeters of 1:2000 prostigmine methylsulphate, but motility initiated in 8 such experiments on 4 dogs resulted in defecation (Table I).

Drug actions on the colon of man. In the experiments on the human subject the blood pressure and heart rate were recorded at 5 and

then 10 minute intervals during the first hour after injection of the drugs.

Pituitrin. Man. In 31 experiments, surgical pituitrin in doses of 1 to 2 units was injected intramuscularly into the 4 subjects. Within 3 minutes after injection (Figure 2, A) and in 28 instances strong co-ordinated type II contractions resulted, which were sensed by the subjects and culminated in the expulsion of material and flatus from the colostomy. The action of pituitrin in this dosage usually persisted for 15 to 20 minutes. In 2 experiments the response was slight; in 1 instance the pituitrin had no discernible effect.

As indicated in Table II, the total motility during the first 50 minute period was slightly below the control level, but there was a decided increase in propulsive motility. With these small doses the blood pressure and heart rate were not changed and the subjects had no sensations other than those associated with propulsion of colon contents.

Physostigmine sulphate. Man. Twenty experiments were conducted in which physostigmine in doses of 1, 2, or 3 milligrams were injected intramuscularly. Expulsion of colon material and flatus occurred in from 20 to 40 minutes after injection due to an increase in total and propulsive motility (Table II). With 1 milligram the results were variable in the different subjects. One patient was nauseated on 3 occasions, and vomited during one period 2 hours after injection. The colon of a second patient showed no reaction to the injection of 1 milligram of physostigmine and he manifested no side effects. On other occasions he was given 2 to 3 milligram injections and both the propulsive and nonpropulsive motilities were decidedly increased. Heart rate and blood pressure were not changed with these doses nor did he have sensations other than those resulting from increased colon motility.

If the dose of physostigmine is sufficient to initiate colon motility, the stimulation may persist for several hours after injection (Table II). When the doses were graded for each subject, physostigmine acted on the colon without producing side reactions. However, no correlation was found between the weight of the patient and his tolerance to physostigmine. Furthermore, the reaction of the colon to 1 milligram of the drug varied in the same individual on different occasions. Therefore, an accurate correlation between these dosages and effect on colon motility was not evident.

Simultaneous injection of pituitrin and physostigmine sulphate. Man. In 22 experiments, 1.25 units of surgical pituitrin plus 0.7 to 1 milligram of physostigmine were injected simultaneously. Pituitrin action appeared within a few minutes and endured for about 20 minutes. Following the action the physostigmine effect became manifest and lasted for several hours. It seems significant that whereas 1 milligram of physostigmine used alone failed to produce a good motor effect in this one patient referred to previously, on 3 of 6 occasions a good motor reaction resulted from the physostigmine when combined with pituitrin. The second patient who was nauseated by 1 milligram of physostigmine manifested a good motor response without nausea to 0.7 milligram plus 1.25 units of pituitrin. In the 2 remaining patients no definite evidence of synergistic action of the 2 drugs was obtained but there was no doubt regarding the supplementary effects of the 2 drugs.

With physostigmine alone in adequate dosage, especially with the combination of pituitrin and physostigmine, facilitation of the gastrocolic reflex to a meal ingested 2.5 hours after injection was almost uniformly observed.

Prostigmine methylsulphate. Man. Prostigmine methylsulphate in doses of 1 cubic centimeter of a 1:4000 solution (0.25 mgm.) and 1 cubic centimeter of a 1:2000 solution (0.5 mgm.) was given intramuscularly in 30 experiments of 150 minutes duration (Table II). Twelve of these experiments on 4 subjects using the 0.25 milligram dose resulted in augmented motility in 7 instances. There was an increase in both the total and propulsive motility. With this dose, however, the time of onset of action was variable. The shortest latent period was 20 minutes and the longest 1.0 hours. Tonus during the period of observation was sometimes, but not uniformly, increased. In 3 instances the increase in total and propulsive motility was slight, and in 2 there was no apparent effect. The latter 2 and 1 of the former 3 occurred in same patient who was not affected by 1 milligram physostigmine.

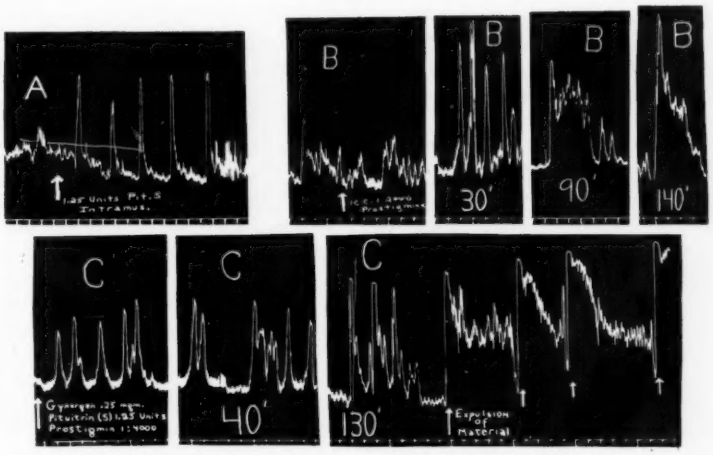

Fig. 2. A, Propulsive motility in the colon of man initiated by 1.25 units surgical pituitrin injected intramuscularly; B, propulsive and nonpropulsive motility in the colon of man after intramuscular injection of 1 cubic centimeter of prostigmine 1:2000 (0.5 mgm.); C, motility after simultaneous intramuscular injection of gynergen (ergotamine tartrate 0.25 mgm.), surgical pituitrin (1.25 units), and 1 cubic centimeter prostigmine 1:4000 (0.25 mgm.). The last 4 arrows indicate expulsion of material from the colon.

Eighteen injections of prostigmine methylsulphate (0.5 mgm.) were made in the 4 subjects. In all cases there was a definite increase in propulsive and total motility (Figure 2, B) for several hours (Table II). However, as with the smaller dose there was variation in the time of onset of motility. The shortest latent period was 12 minutes and the longest 80 minutes. Facilitation of the gastrocolic reflex was definite in 14 of the experiments. There were no side reactions or definite changes in heart rate and blood pressure encountered in any experiment with prostigmine methylsulphate in these dosages. One cubic centimeter of prostigmine 1:4000 (0.25 mgm.) was found to be about as effective in activating the colon segments as 0.5 milligram of physostigmine sulphate, while 0.5 milligram of prostigmine was equivalent to 1 milligram of physostigmine in 3 patients and apparently better in 1.

Prostigmine bromide tablets (15 mgm.). Man. One tablet containing 15 milligrams of prostigmine bromide was administered by mouth in 16 experiments. During the experimental time (3 hours) the drug in 11 instances produced no decided action (Table II). On 5 occasions the action appeared about 2 hours after administration, as evidenced by an increase of total and propulsive motility with expulsion of material. These facts do not indicate that the drug is not effective by mouth because in all cases except one, the subjects reported the repeated evacuation of colon contents when they were at home. This action appeared during a period 5 to 8 hours after the tablet was given, and a decided increase in this effect followed ingestion of a meal.

Prostigmine methylsulphate (0.25 mgm.) plus pituitrin (1.25 units). Man. In all of 16 experiments, the combination of 0.25 milligram of prostigmine methylsulphate and 1.25 units of pituitrin injected intramuscularly caused an increase in total and propulsive motility and resulted in the expulsion of colon material and flatus. The expulsion of material occurred within a few minutes and continued for several hours, the initial response being due to the pituitrin and the continued response to prostigmine. As in the experiments in which pituitrin was combined with physostigmine, it was difficult to be certain of synergistic action, since each drug is individ-

ually effective. However, in all cases the action of prostigmine (0.25 mgm.) seemed to be more effective in expelling colon contents when combined with pituitrin than in those experiments in which it was injected alone. No side reactions or changes in blood pressure or heart rate were noted with this combination.

Ergotamine tartrate solution and tablets (Gynergen). Man. In 12 experiments ergotamine tartrate was injected in doses of 0.25 milligram, with no discernible effect on the colon. In 6 additional experiments 1 tablet of gynergen (1 mgm.) was given by mouth. Our motility records showed no deviation from normal expectancy, nor were latent actions on colon reported by patients. With these dosages no side reactions occurred.

In 14 experiments on the dog it was found that 0.35 milligram of ergotamine tartrate (0.0097 to 0.0184 mgm. per kilogram) given intramuscularly caused an increase in both the propulsive and nonpropulsive motility. In 7 instances the increased motor activity culminated in defecation. However, the human subjects varied from 63 to 86 kilograms; therefore, on the basis of body weight the dogs received 4 to 6 times as much ergotamine.

Ergotamine tartrate (0.25 mgm.) plus prostigmine methylsulphate (0.25 mgm.). Man. As indicated above ergotamine in 0.25 milligram doses injected intramuscularly had no action on the motility of the colon. However, when this dosage of ergotamine was combined with 0.25 milligram prostigmine methylsulphate in all of 12 experiments a potentiation of the prostigmine action resulted. The motility initiated by this combination was even more propulsive than that resulting from 0.5 milligram prostigmine (1 c.c. of 1:2000 solution) when used alone. Motility appeared on an average much sooner (28 min.) and apparently had an increased capacity to move colon contents. The total quantity of motility initiated was about the same as that observed after prostigmine (0.5 mgm.), but the propulsive motility was somewhat increased (Table II). This propulsive motility was very powerful. On two occasions *the most proximal balloon was tied into a simple knot,* even though the tube and balloon were reinforced by a flexible steel spring. Facilitation of the gastrocolic reflex to a meal ingested several hours later was definite in all 4 subjects.

In 8 additional experiments, after a control period of 30 minutes, 1 tablet of ergotamine tartrate (1 mgm.) was given simultaneously with 1 tablet of prostigmine bromide (15 mgm.). In an average time of about 90 minutes the action of the prostigmine bromide became evident. Although the effect of the drugs together did not last longer than the prostigmine bromide alone, the response was more marked and was associated with repeated expulsion of fecal material and flatus.

Five of the experiments were conducted during the morning session and facilitation of the gastrocolic reflex to lunch was evident. An increased motility during the afternoon session was graphically recorded. Both the nonpropulsive and propulsive motilities were increased. The 3 remaining experiments of this series were conducted in the afternoon. The patients, however, reported facilitation of the gastrocolic reflex to their dinners 6 hours later, as indicated by repeated evacuations of colon contents.

Simultaneous administration of prostigmine methylsulphate, pituitrin, and ergotamine tartrate. Man. Table II presents the results of 12 experiments in which a combination of ergotamine tartrate (0.25 mgm.), prostigmine methylsulphate (0.25 mgm.), and pituitrin (1.25 units) was injected simultaneously. An increase in both total motility and propulsive motility resulted, the latter being very definitely increased and causing the expulsion of colon contents. The enhanced motility was evident within a few minutes, due to the pituitrin action, and endured for several hours due to the marked synergistic action of the ergotamine and prostigmine. Only 12 experiments were conducted because of the potency of the mixture. *On 3 occasions the proximal balloon was tied into a simple knot.* This occurred immediately after very strong type II propulsive waves which caused expulsion of colon contents and sometimes the balloon and tube (Figure 2, C).

Most important is the fact that this strong action on the colon was not accompanied by side effects. The subjects felt well, with no significant changes in pulse rate or blood pressure.

EVALUATION

The importance of distinguishing between the two functional types of motility, propulsive and nonpropulsive, is confirmed by certain observations presented in this as well as in previous papers (1, 3, 4). For example, it has been shown that morphine sulphate (16 mgm.) increases the total motility and tonus of the distal colon and the ileum of man (2). However, the increase in total motility is the result of an increase in motility of the nonpropulsive type; the propulsive motility and discharge of colon contents is markedly decreased. In the present work if we had given attention only to the recording of total motility we should have concluded that pituitrin decreased or had little effect on the motility of the colon. The records of propulsive motility, however, showed that propulsive motility and discharge of contents from the colostomy were increased for a short period after injection of a small quantity of pituitrin. Physostigmine sulphate and prostigmine methylsulphate are examples of drugs which stimulate both functional types of motility. Thus we have examples of *3 types of drug action on the colon: one exemplified by morphine in which the chief effect is an increase in nonpropulsive and a decrease in propulsive motility; a second exemplified by pituitrin in which the chief effect is an increase in propulsive motility with little or no increase in the nonpropulsive; and a third exemplified by prostigmine in which both types of motility are increased.*

The importance of using, at least in some experiments, a tandem balloon system in studying drug action on the colon is confirmed by observations made in this work. In a previous study it was observed that effective propulsive motility (the transportation of contents) is dependent upon the existence of co-ordination between adjacent segments. That is, if distal adjacent segments of the colon manifest high tonus, or types of motility not conducive to co-ordination of activity, the appearance of a propulsive wave in a proximal (oral) segment will not be propagated onto the adjacent distal segment to effect transportation of colon contents. In such instances, if the propulsive wave in the proximal segment is high grade and does not "pass onto" the distal segment, the patient reports a "cramp-like sensation." This has been referred to as dyskinesia. In a number of instances dyskinesia was observed and a "cramp-like" sensation was reported after 1 milligram of physostigmine. No contents were passed from the colostomy. Contents were present in the colon, since later a wave of no greater amplitude than formerly would arise, be propagated to the distal segment and contents would be expelled. Any existing cramp-like sensation would then disappear.

Prostigmine methylsulphate and pituitrin in the doses used in our subjects, appeared to promote a co-ordinated type motility between segments, resulting in propulsion of contents. Propulsive waves were quite uniformly propagated and cramp-like sensations were not reported. It is entirely possible that in some subjects, depending upon the degree of dyskinesia existing between adjacent segments of the colon, the amount of gas present and the consistency of the colon contents, the same doses of the two drugs might cause cramp-like distress. It must be remembered here that our studies were made on presumably normal colons under uniform, controlled conditions.

The combination of *physostigmine sulphate with pituitrin* resulted in the addition of the effects of each. The rather prompt and transient action of pituitrin in the small dose used, was followed by the more delayed and prolonged action of physostigmine. The only evidence of synergistic action was observed in 1 patient who did not respond to 1 milligram of physostigmine alone, but did to the combination of pituitrin and physostigmine. The same was true of the *prostigmine methylsulphate with pituitrin* combination. This latter combination is to be preferred since doses of prostigmine (0.25 mgm.) and pituitrin (1.25 units) which caused strong propulsive movements gave no side reactions as do similarly effective doses of physostigmine.

Ergotamine tartrate (0.25 mgm.) alone had no significant effect on the motility of the colon of our subjects. When ergotamine tartrate was combined with prostigmine methylsulphate (0.25 mgm.) the action of prostigmine was definitely augmented, i.e. 0.25 milligram of prostigmine was as effective as 0.5 milli-

gram given alone. Contents were still being discharged at the end of a 3 hour period of observation and the "gastrocolic" reflex was facilitated; this indicates that the propulsive motility of the small intestine was also augmented. Ergotamine tartrate and prostigmine were combined on the presumption that the ergotamine would increase the excitability of the colonic musculature by direct action and hence augment the response to prostigmine. This explanation may be too simple, but is supported by the observation that ergotamine increases the sensitivity of the intestine to distention and the initiation of peristalsis (27). From the results on the "normal" colon, this combination, we believe, should be tried clinically in cases of postoperative distention.

The most effective combination, in regard to the duration of action appeared to be ergotamine tartrate (0.25 mgm.), prostigmine methylsulphate (0.25 mgm.) and pituitrin (1.25 units). It was effective, and our subjects complained that, after receiving this combination, material was intermittently discharged from the colostomy for 6 to 8 hours after injection. With the combination of the 3 drugs the most powerful propulsive contractions we have recorded (Fig. 2, C) occurred. As noted before, in 3 instances these contractions tied the most orally located balloon into a simple knot. No cramp-like distress or side reactions were reported to accompany the powerful propulsive motility initiated by this combination. We believe that this combination should also be studied in adynamic ileus and megacolon since the duration of action on the colon of 4 normal subjects extended over a period of 6 to 8 hours.

The concept of functional segmental motor activity of the colon. Our observations show that the colon is composed of functional segments which cannot be described on a structural basis. Anatomically the segments of the colon are usually referred to as the ascending, transverse, descending, and sigmoid colon. On the basis of motor activity, the colon is composed of small or large divisions depending on the type of motility which is being manifested at any particular time. When 3 centimeters (length) balloons in series are placed 7 centimeters apart, 2 adjacent segments may manifest different types of motility. In this sense each segment represents a functional unit. When 2 adjacent segments manifest the same general type of motor activity so that a wave conducive to propelling material is propagated from one to the other, then the 2 segments represent an integrated or coordinated functional unit. In a "mass peristalsis" as in defecation, an entire anatomic division of the colon represents a functional unit, so that occasionally a "mass peristalsis" starting in the distal transverse colon may pass over a number of segments in sequence, including the rectum.

We have no information regarding the presence or absence of motility in the segments of the colon between the balloons, except when a propagated wave passes from one balloon-containing segment to another. In man, a single haustrum or a group of adjacent haustra may represent a functional motor unit, and the balloon may record the activity of the local group of haustra. Thus, a local type II contraction may represent propulsion from, or an attempt to propel material from, one haustrum to another. The type I contractions represent the nonpropulsive activity of the haustra exposed to the balloon. The change of a type I into a segmental type II wave which is not propagated to the adjacent balloon-containing segment would indicate that some stimulus has caused the local haustra to become co-ordinated so that local propagation of a wave for a short distance can and does occur. For a "mass peristalsis" the coordination must spread in sequence from one haustrum or group of haustra to another, or the original stimulus must in some way exert a widespread integrating influence, probably sequential, on the more distal segments of the colon. The rise in tone or wave-like sustained contraction manifested in the type III activity must represent a simultaneous contraction of several haustra, since it is difficult to visualize how the contraction of a single haustrum could produce the observed mechanogram.

This concept of the functional segmental motor activity of the colon serves as a basis for the explanation of the normal physiological activity of the colon and readily explains the findings or results of the so called unstable or

irritable colon, which represents a dyskinesia of the colon. This concept requires that, if a drug is to be effective in adynamic ileus, it must not only increase the tone of the musculature but must also act so as to facilitate the genesis and propagation of propulsive waves from one segment to another. A drug that would only increase tone and nonpropulsive motility would lead only to a churning and local pooling of the contents giving a "sausage-string" effect. Considering the duration of action and the absence of side effects, prostigmine methylsulphate is the best single drug among those studied, for the genesis and propagation of propulsive waves from one segment to another. The other drugs as pituitrin and ergotamine tartrate may be used to supplement or potentiate prostigmine methylsulphate.

SUMMARY AND CONCLUSIONS

The functional motor activity of the canine and human colon can be best described as being propulsive or nonpropulsive in character. The relation between the types of contractions recorded by the balloon method and the functional result has been outlined.

The data obtained in 70 control studies on 4 human subjects with colostomy show that the propulsive motility in the distal colon constitutes on the average about 10 per cent of the total motility. This value is similar to that obtained in 4 dogs, the average being about 13 per cent. The effects of single drugs and their combinations were analyzed for the extent of change in the 2 types of functional activity. All solutions were given intramuscularly; the tablets were given by mouth.

1. Pituitrin in the relatively small dosage of 1 to 2 units caused an increase in the propulsive motility of the human distal colon but did not on the average increase the total motility above the control. In the dosage used its action usually did not last longer than 20 minutes. The action of pituitrin on the colon of the unanesthetized, trained dog with appendicostomy was opposite to that on the human colon. Doses of 1, 2, or 5 units invariably depressed motility and sometimes tonus. This depression, depending upon the dose, was manifest for from 30 minutes to several hours, the distal colon being more affected than the proximal.

2. In doses of 1 milligram, physostigmine sulphate increased the total and propulsive motility of the canine and human colon. It was difficult to grade the dosage so as to avoid side reactions and yet stimulate adequately the propulsive motility of the colon.

3. The simultaneous injection of 1 to 2 units of pituitrin and 0.7 to 1.0 milligram of physostigmine sulphate resulted usually in a supplementary action on the human colon. In 3 subjects the pituitrin acted first, increasing propulsive motility and was followed by physostigmine action which increased both propulsive and nonpropulsive motilities. In one subject there was an apparent synergistic action because in 3 of 6 instances 1 milligram of physostigmine when injected alone elicited no definite colon response.

4. Prostigmine methylsulphate in doses of 0.25 milligram was approximately equal in its action to 0.5 milligram of physostigmine on the motility of the human and canine colon. The 0.25 milligram dose was not effective in all experiments. When the dosage was increased to 0.5 milligram effective propulsive motility resulted in all cases. The nonpropulsive motility was also increased. No side effects were noted with either of the above dosages in dog or man.

5. Prostigmine bromide tablets (15 mgm.) given orally to the 4 human subjects resulted in an increase in total and propulsive motility, during the experimental time (150 min.), on only 5 occasions. In 10 experiments increased expulsion of colon material occurred 5 to 8 hours after administration. In 1 instance there was no effect.

6. The simultaneous injection of prostigmine methylsulphate (0.25 mgm.) and pituitrin (1.25 units) resulted in an increase of propulsive as well as nonpropulsive motility of the human colon. The pituitrin in this dosage initiated propulsive motility which lasted for about 20 minutes, then the prostigmine action appeared and usually endured for several hours. In 1 patient synergistic action apparently occurred since in all cases when the 2 drugs were injected simultaneously the response to prostigmine was definite, whereas

in those experiments in which 0.25 milligram of prostigmine methylsulphate alone was used the response was not definite.

7. Injection of ergotamine tartrate (0.25 mgm.) intramuscularly or 1 tablet (1 mgm.) by mouth had no discernible effect upon the colon of 4 human subjects with colostomy.

8. The simultaneous injection of ergotamine tartrate (0.25 mgm.) and prostigmine methylsulphate (0.25 mgm.) resulted in potentiation of the prostigmine. Both nonpropulsive and propulsive motilities were increased above that initiated with prostigmine (0.25 mgm.) alone.

9. Ergotamine tartrate in tablet form (1 mgm.) and prostigmine bromide in tablet form (15 mgm.) given simultaneously by mouth to the 4 human subjects resulted in the appearance of strong propulsive motility in from 1 hour to several hours after administration. The duration of action was not longer than that of 15 milligrams prostigmine bromide alone, but the greater efficiency in initiating propulsive motility which evacuated colon contents was evident.

10. The simultaneous intramuscular administration of ergotamine tartrate (0.25 mgm.), prostigmine methylsulphate (0.25 mgm.), and surgical pituitrin (1.25 units) resulted in the appearance of propulsive motility within a few minutes due to pituitrin action, and the subsequent continuation of strong propulsive motility attributable to the potentiation of prostigmine by ergotamine.

11. Physostigmine sulphate, prostigmine methylsulphate, and the combinations of prostigmine with ergotamine and pituitrin facilitated the gastrocolic reflex to a meal ingested several hours after administration of the drugs.

12. It is believed that a combination of ergotamine tartrate (0.25 mgm.), prostigmine methylsulphate (0.25 mgm.), and pituitrin (1.25 units) should prove to be more effective in the management of postoperative distention than any of the drugs used alone. On the basis of duration of action, the absence of side reactions with doses which are effective in producing strong propulsive motility, prostigmine is ranked as the best single drug yet investigated.

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AMPUTATION OF THE LOWER EXTREMITIES IN OCCLUSIVE ARTERIAL DISEASES

A Ten Year Review

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THIS report is based on a study of those cases observed at the Mayo Clinic in 10 years, in which occlusive arterial disease of the lower extremities was treated by amputation. In order to make a comprehensive study we reviewed the records in groups of cases in which, respectively, the clinical diagnosis was thromboangiitis obliterans, arteriosclerosis obliterans associated with diabetes, arteriosclerosis obliterans alone, and acute arterial occlusion. There were features common to all these groups, however, which should be considered (Table I).

The diagnosis of occlusive arterial disease of the lower extremities is based on the finding of diminished to absent pulsation in the femoral, popliteal, posterior tibial, and dorsalis pedis arteries. Confirmatory evidence, as would be expected, is noted more easily in the distal end of an extremity and may vary from lowered surface temperature of the part to ulcers, gangrene of the digits or frank gangrene of the foot in the more advanced cases. The most characteristic symptom is claudication, which is an aching or cramplike sensation occurring chiefly in the calf of the leg. Claudication is brought on by exercise and is relieved by rest. Other symptoms described by the patient may be coldness of the feet, a tingling sensation in the toes or changes in color such as pallor and rubor.

The diagnosis in advanced cases of occlusive arterial disease is not difficult. In early cases or in those of mild involvement, the arteries should be carefully examined as to quality of pulsation, and the skin should be observed for abnormal pallor when the affected extremity is elevated for a few minutes, for slow return of color when the extremity is placed in dependent position after elevation, and for abnormal rubor when it has been in the dependent position for a few minutes. All these manifestations are pathognomonic of an occlusive process of the arteries.

In selecting the site for amputation, the surgeon should not be too strictly governed by standard levels, but should be guided by the blood supply as noted by means of exploratory incisions at the time of surgical intervention. Naturally, it is safer in any case of occlusive arterial disease to perform amputation above, or at the level of, the knee joint. However, in the case of a young person who has an arterial disease such as thromboangiitis obliterans, an attempt to secure a satisfactory stump below the knee should be made when there is a reasonable chance to secure satisfactory healing. More will be said on this subject when thromboangiitis obliterans is considered.

One type of amputation of lower extremities has been employed at the clinic fairly consistently throughout. In the thigh, a long anterior and a short posterior flap are used, with corresponding incisions throughout the muscles and fascia. The vessels are ligated doubly and the nerves are identified and injected. In some instances alcohol is used for injection, whereas in other instances 10 cubic centimeters of a 1 per cent solution of procaine hydrochloride is injected into the nerve both before and after it is severed. To our knowledge, neuromas have not formed in those cases in which procaine hydrochloride has been injected, but as to the question of the superior efficacy of either substance there is no definite proof.

In amputation below the knee a long posterior and a short anterior flap are used. The crest of the tibia is beveled and the fibula is

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TABLE I.—AMPUTATION OF LOWER EXTREMITIES FOR OCCLUSIVE ARTERIAL DISEASE —GENERAL STATISTICS

Item	Quantity
Patients, number	240
Average age, years	56
Primary amputations, number	264
On males	228
On females	36
Through thigh	165
Below knee	97
Through knee (Gritti-Stokes)	2
Reamputations, number	33
Postoperative gas gangrene infections, number	11
Deaths	5
Deaths in entire series, number	24
Mortality rate, per cent	
Based on number of patients	10
Based on primary amputations	9
Based on total amputations	8

sectioned at a level 1 inch to 2 inches (2.5 to 5 cm.) higher than the tibial amputation. When amputation is made less than 5 inches (13 cm.) below the knee the prosthesis is worn with more comfort if the fibula is fixed to the tibia or if the remaining fibular fragment is excised. Drains are employed in those cases in which there is associated lymphangitis or spreading cellulitis. The wounds are closed snugly.

We noted that in all groups of occlusive arterial disease, if there is present an open lesion with gangrenous tissue, one complication is potential; that is, gas gangrene infection. Such a complication followed 4.1 per cent of the primary amputations which were performed (Table I). Among the 11 patients represented by these 11 amputations, there were 5 deaths, 3 of which occurred in the group of cases of arteriosclerosis obliterans without associated diabetes. Amputation in 2 of these 3 cases was carried out, respectively, at the lower and at the middle third of the thigh and in the third case, below the knee. In 2 of the 3 cases death was attributed directly to gas gangrene infection. Death in the third case occurred as the result of pneumonia on the 18th day after operation, at which time the gas gangrene infection had been controlled; however, one must consider the infection as contributing to the death. Death in the 2 other of the 5 cases occurred in the diabetic group and was attributed directly to gas gangrene infection. One of these 2 patients had undergone amputation through the thigh and the other below the knee.

From the clinical observation of the formation of gas in the soft tissues and from the recovery of Clostridium welchii from culture in several cases of vascular disease in which gangrene and infection developed about the toes and feet, we believe that in every case in which an open lesion is associated with gangrene and infection, postoperative gas gangrene infection is likely to occur. Prior to surgical operation, the patients appear to possess a defense mechanism against the local presence of the organism, as is evidenced by the absence of generalized symptoms of such a malignant infection. It is likely that the superficial position of the bacteria plays a rôle in their failure to produce general symptoms. In those cases in which virulent gas gangrene infection develops after surgical intervention, the symptoms of undue pain, elevated temperature, and rise in pulse rate are manifest, usually within 24 to 36 hours, and inspection of the stump is warranted. A less virulent infection may develop several days after amputation. The organism may be introduced into the wound at the time of amputation or may be present in the lymphatic spaces before operation. Needless to say, the stump, with its traumatized muscle and fascia and some inevitable postoperative bleeding, is a fertile field for the organism regardless of its point of entrance. With definite evidence of the presence of Clostridium welchii in the foot before surgical operation, one is inclined to believe, if postoperative infection develops, that the organism may have been in the tissue locally and that its action may have been hurried by the surgical procedure, which provided the anaerobic condition necessary for the bacterial growth. In our experience stumps have not been protected from gas gangrene infection by prophylactic polyvalent perfringens antitoxin.

THROMBOANGIITIS OBLITERANS

Thromboangiitis obliterans, more commonly referred to as Buerger's disease, is a condition resulting from chronic inflammation of the blood vessels with formation of thrombus and a resultant decrease in arterial circulation to the affected part.

TABLE II.—THROMBOANGIITIS OBLITERANS—SITE OF PRIMARY AMPUTATION AND PRESENCE OR ABSENCE OF POSTOPERATIVE COMPLICATION

Complication	Patients or procedure	Site of primary amputation						Totals
		Below knee		Through thigh		Through knee (Gritti-Stokes)		
		Patients*	Primary amputations	Patients*	Primary amputations	Patients*	Primary amputations	
Present	Patients*	25		3		1		29
	Primary amputations		25		3		1	29
Absent	Patients*	33		26		1		60
	Primary amputations		38		29		1	68
Total		58	63	29	32	2	2	

*The number of patients represented in this table adds to 89. Actually there were only 83 patients. The discrepancy arose because 6 patients underwent primary amputation of one lower extremity without complication resulting but also underwent primary amputation of the other lower extremity with complication resulting. These 6 patients are counted both in the group in which complications were present and in that in which they were absent.

Thromboangiitis obliterans affects, primarily, middle aged persons. It occurs chiefly among men, although it is not confined to males as has been previously thought. However, there were no women in the group of patients who, in the ten years from 1930 to 1939 inclusive, required amputation of one or both lower extremities for thromboangiitis obliterans at the clinic. If either lower extremity must be removed for this disease, the patient should plan for a stay in the hospital of about 3 weeks. For our group of 60 patients whose recovery was uncomplicated (Table II) the average period of hospitalization, after the primary surgical intervention, was 21 days. Various methods of anesthesia may be used.

Little need be said, in addition to what is shown in Table II, concerning the site of primary amputation and the incidence of postoperative complications. The nature of the complications and the necessary secondary measures, however, have a bearing on the results and merit some remark.

Of the 25 primary amputations below the knee, which resulted in complications (Table II), 22 were followed by reamputation and 3 were not. Of the 22 reamputations, 7 were below the knee and 15 above. Following 2 of the 7 amputations and 3 of the 15 amputations just mentioned, gas gangrene infection occurred. In 1 of these 5 cases of gas gangrene, the blood stream became infected. Concerning the 25 amputations mentioned in the first sentence of this paragraph it has been indicated that following 3 of them reamputation was unnecessary. Of these 3 amputations, subsequent to 2 of them, infection took place and subsequent to the third, a slowly healing ulcer developed.

Referring to Table II again: Of the 3 primary amputations through the thigh, which resulted in complications, 1 was followed by reamputation and 2 were not. Of the 2 instances just mentioned, the complication consisted in infection in one and a slowly healing ulcer in the other. The one amputation through the knee (Gritti-Stokes), which is found in the same category in Table II as the cases just considered, was followed by reamputation.

From what has just been said of reamputation, as well as from what is evident in Table II concerning the site of primary amputation, those who previously have been interested in the subject will deduce that in this group of middle aged men, more careful effort is made to amputate at the lowest level of circulatory adequacy than in any other group of patients. Although application of this principle results in a relatively high percentage of reamputations, there were no deaths in the group just reported; only one general complication occurred, and a serviceable stump below the knee was obtained in 76 per cent of the cases. We believe that this result justifies trial of primary amputation below the knee in a large percentage of those cases of thromboangiitis

TABLE III.—ARTERIOSCLEROSIS OBLITERANS WITHOUT DIABETES—SITE OF PRIMARY AMPUTATION, PRESENCE OR ABSENCE OF POSTOPERATIVE COMPLICATIONS AND THE MORTALITY

Complication	Patients or procedures	Site of primary amputation				Totals	Deaths
		Below knee		Through thigh			
		Patients*	Primary amputations	Patients*	Primary amputations		
Present	Patients*	6		16		22	13
	Primary amputations		6		16	22	
Absent	Patients*	8		52		60	0
	Primary amputations		9		54	63	
Totals		14	15	68	70		

*The number of patients represented in this table adds to 82. Actually, there were only 80 patients. The discrepancy arose because 2 patients underwent primary amputation of one lower extremity without complication resulting but also underwent primary amputation of the other lower extremity with complication resulting. These 2 patients are counted both in the group in which complications were present and in that in which they were absent.

obliterans in which amputation must be performed.

ARTERIOSCLEROSIS OBLITERANS WITHOUT DIABETES

In our series of surgical amputations for vascular deficiencies the cases in which diagnosis was made of arteriosclerosis obliterans without diabetes rivaled in number the cases of thromboangiitis obliterans. Clinically, however, these 2 conditions presented wide variance in statistical findings.

Seventy of the patients were males and 10, females. Because of the advanced age of these patients, one would anticipate the presence of complicating conditions. Acceptable methods of anesthesia, therefore, are fewer than the methods acceptable in cases of thromboangiitis obliterans. We favor spinal anesthesia in the presence of arteriosclerosis obliterans.

As is indicated in Table III, of the 22 patients who experienced postoperative complications, 13 died. Of these 13 patients, 12 had been subjected to primary amputation through the thigh and of one the primary amputation was below the knee. The death of 3 of the 13 patients was attributed to bronchial pneumonia; of 2, to coronary disease with congestive heart failure; of 2 others, to cerebrovascular accidents; of 2, to uremia; of 1, to multiple emboli; and of 3, to gas gangrene infection. These are in contradistinction to 5 cases of thromboangiitis obliterans in which gas gangrene infection occurred after surgical intervention, with no resultant deaths.

In the 9 remaining instances of the 22 in which postoperative complications occurred, the difficulty arose in healing of the stump. In 3 instances in which postoperative complications occurred and reamputation was not required, convalescence after primary amputation through the thigh was complicated by slow healing because of circulatory deficiency. Six patients, or approximately 8 per cent of the 80 patients in this group, were subjected to reamputation before a satisfactory stump was obtained. It is interesting to note that 4 of the 6 reamputations were done on patients who had been subjected to primary amputation below the knee. The outstanding fact brought out in this series of 80 cases then is that, because of the 2 interdependent factors of advanced age and consequent complicating conditions, 82 per cent of the primary amputations were through the thigh (Table III). Amputation below the knee should be reserved for the younger patients.

ARTERIOSCLEROSIS OBLITERANS WITH ASSOCIATED DIABETES

Arteriosclerosis obliterans with associated diabetes furnished the third largest number of cases in our series of amputations for occlusive arterial disease. In this group patients were in their late years of life. The proportion of men was not so marked as it was in the preceding groups of thromboangiitis obliterans and arteriosclerosis obliterans without diabetes. However, this group again demonstrates the preponderance of men among pa-

TABLE IV.—ARTERIOSCLEROSIS OBLITERANS WITH ASSOCIATED DIABETES—SITE OF PRIMARY AMPUTATION AND PRESENCE OR ABSENCE OF POSTOPERATIVE COMPLICATION

Complication	Patients or procedures	Site of primary amputation				Totals	Deaths
		Below knee		Through thigh			
		Patients*	Primary amputations	Patients*	Primary amputations		
Present	Patients*	9		9		18	7
	Primary amputations		9		9	18	
Absent	Patients*	10		35		45	0
	Primary amputations		10		38	48	
Totals		19	19	44	47		

*The number of patients represented in this table adds to 63. Actually there were only 61 patients. The discrepancy arose because 2 patients underwent primary amputation of one lower extremity without complication resulting but also underwent primary amputation of the other lower extremity with complication resulting. These 2 patients are counted both in the group in which complications were present and in that in which they were absent.

tients who are suffering with arterial disease, as 42 of the patients were men and 19 were women.

We favor employment of spinal anesthesia. The size of the dose should be governed by the general condition and size of the patient. It is better to err in the giving of an insufficient amount of anesthetic agent for completion of the operation and to rely on supplemental agents, such as pentothal sodium, than to give large doses of the spinal anesthetic substance.

As is indicated in Table IV, 72.7 per cent of the primary amputations were followed by an uncomplicated postoperative course. Of the 18 patients who experienced postoperative complications, 7 died. Five of these 7 patients had been subjected to primary amputation through the thigh and of 2 of the 7, the primary amputation was below the knee. The deaths of 2 of the 7 patients were attributed to bronchial pneumonia; of 2, to unknown cause; of 1, to renal failure; and of 2, to gas gangrene infection. Both of the patients who died from gas gangrene infection underwent previous amputation below the knee.

In the 11 remaining cases of the 18 in which postoperative complications occurred, the difficulty arose in healing of the stump. In 6 of the 11 cases, convalescence was complicated by slow healing as a result of inadequate circulation. The postoperative course of 3 patients was complicated by infection and sloughing. In the 2 remaining cases of the 11, the complications were inadequate circulation and gas gangrene infection, respectively; both of these patients were subjected to primary amputation below the knee, and both were subjected to reamputation. Nine, or 47.4 per cent, of the 19 primary amputations below the knee were followed by complications.

The obvious fact brought out in our series of patients with arteriosclerosis obliterans is that the association of diabetes did not increase the mortality rate but that this was found to be less than the mortality rate in those cases of arteriosclerosis obliterans without associated diabetes. This fact may be attributed to the close co-operation of the internist and the surgeon, both in the preoperative preparation and the postoperative care of the diabetic patient. It is further shown that amputations below the knee should be reserved for the exceptional case in the younger patients.

ACUTE ARTERIAL OCCLUSION

The final group of cases, those of acute arterial occlusion, was the smallest group in the series. It is composed of 16 patients (10 males and 6 females) on whom 16 primary amputations were performed, 15 through the thigh and 1 a disarticulation at the hip. There was no case in which bilateral amputation was necessary. Although the patients in this group were young, with an average age of 52 years (Table V, A), they constituted the greatest operative risk and carried the highest mortality rate of any group studied. Ten of the patients presented clinical evidence of severe heart disease before operation, 3 of the 10 having rheumatic cardiac lesions. Among

TABLE V, A.—ACUTE ARTERIAL OCCLUSION
AGE DISTRIBUTION

Age, years	Patients	Per cent
30–39	2	12.5
40–49	6	37.5
50–59	3	18.7
60–69	4	25.0
70 or more	1	6.3
Total	16	100
Youngest, years	38	
Oldest, years	71	
Average, years	52	

TABLE V, B.—ACUTE ARTERIAL OCCLUSION
ANESTHESIA

Type of anesthesia	Patients or amputations	Nonfatal complication present	No complication	Deaths
Spinal	11	2	6	3
Inhalation	3		2	1
Pentothal sodium (intravenous)	2	1	1	
Total	16	3	9	4

the 16 patients there were 4 deaths, a mortality of 25 per cent for the group (Table V, B). One patient died of bronchial pneumonia on the 21st day after operation; the second died on the 1st day after the surgical procedure and a third on the 2nd day, both deaths resulting from cardiac complications. A fourth patient died of cerebral embolism on the 9th day after operation; in this case the wound was healed and the patient had been dismissed; she died at her home. Two of the deaths were of women and 2 of men. In 12, or 75 per cent, of the cases the left lower extremity was involved.

In this group of 16 cases, the femoral artery was occluded in 5; the popliteal artery in 10 and the posterior tibial artery in 1 case. In only 2 of the cases was there any degree of circulatory involvement of the opposite extremity. In cases in which lesions were of the left side, the popliteal artery was occluded in 9; the femoral artery in 2 and the posterior tibial artery in 1 case. Of these patients 6 were men and 6 were women. In cases in which lesions were of the right side, the femoral artery was occluded in 3 and the popliteal artery in 1 case; none of the patients were women and no deaths were reported. The average duration of occlusion before surgical intervention, with the exception of 1 case in which a gangrene infection was of 1 year's duration, was found to be 12.6 days and the average period necessary for healing after amputation was 27.7 days. In 9, or 56 per cent of the cases, the postoperative course was uneventful and primary healing occurred. In 2 cases healing was delayed 38 and 32 days, respectively. In a third case, reamputation was required but healing took place on the 13th day thereafter.

COMMENT AND SUMMARY

We believe that the discrepancy in the mortality rate among the many reports is caused by the difference in environmental factors and in facilities for treatment rather than by differences in surgical technique and the varying capacity of the surgeon. There should be the closest harmony between the internist and the surgeon for the utmost efficiency in handling cases of occlusive arterial disease. Occlusive arterial disease is a condition most frequently seen in men, although it is not uncommon in women. The ratio found in the series we are presenting was approximately 6.5:1. However, a more nearly equal ratio was seen in arteriosclerosis with diabetes and in acute arterial occlusion. Thromboangiitis obliterans rarely affects women.

If the individual with occlusive arterial disease is of a younger age group and more especially if he has thromboangiitis obliterans, one should seek the level of circulatory adequacy for amputation. For the more elderly patients, usually found in one of the arteriosclerotic groups, amputations below the knee should be discouraged.

A complication common to all groups of occlusive arterial disease is gas gangrene infection following amputation, especially in cases in which amputations are done below the knee. As we said early in this paper, the value of prophylactic polyvalent perfringens antitoxin is questionable. The value of therapeutic polyvalent perfringens antitoxin has been proved. Sulfonamide drugs in postoperative infections have been proved valuable adjuncts to the armamentarium of the surgeon. In cases of spreading cellulitis or associated lymphangitis in occlusive arterial disease, one of the sulfonamide preparations may be ad-

vantageously placed in the wound at the time of amputation. In general, wounds should be closed snugly unless there is some definite indication for drainage at the time of the amputation.

Hasty amputation with only emergency preparation before operation is indicated only in cases of gangrene with spreading cellulitis, gas gangrene infection, or gangrene associated with diabetes in which the diabetes is uncontrollable.

Review of the cases of acute arterial occlusion suggests that this condition has a predilection for the left side and in all the cases of our series, amputation below the knee was precluded. In our opinion, acute arterial occlusion is not an emergency condition requiring immediate amputation; in the majority of cases the surgeon may safely wait for establishment of collateral circulation and a line of demarcation. Further, in acute arterial occlusion, one may anticipate a high mortality rate. This is explained by the fact that the condition which necessitates amputation is, as a rule, a complication of some underlying severe systemic pathological change.

EXTERNAL BILIARY FISTULAS

A Study of 23 Cases

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PERSISTENT external fistulas occasionally follow surgical attacks on the extrahepatic biliary system. These tantalizing complications annoy the patients and harass the surgeons for both realize that the primary operations have failed to remove the obstructive lesions which were interfering with the free flow of bile and associated secretions into the duodenum. Corrective therapy requires the removal of the obstructions or the formation of new biliary channels.

This study is based on an analysis of 23 cases of postoperative biliary fistulas which have followed routine operations for gall stones. Etiologically they may be divided into three groups: those due to incomplete removal of the primary obstructions, those caused by surgical accidents, and those in which the external sinuses were planned for decompressive purposes only.

Incomplete primary operations accounted for 88 per cent of the persisting fistulas. This means that the provocative obstructions were not removed, either because the operators did not recognize them, or were incapable of performing the necessary corrective procedures. Ninety-five per cent of the initial explorations were for gall stones but in 20 instances these elusive calculi were incompletely removed. In 12 cases, 60 per cent, stones were left in the common bile duct; in 6 instances, 26 per cent, they were not removed from the gall bladder; in 1 patient multiple stones were left in the cystic duct, and in another they were overlooked in both the gall bladder and cystic duct. In every instance the operative notes stated that "all stones had been removed" and it was not until the draining sinuses refused to heal that true appraisals were made.

From the Surgical and Roentgenological Services of the Dr. Groves Memorial Latter Day Saints Hospital.

It was interesting to note that 57 per cent of the external fistulas followed cholecystostomies while only 43 per cent occurred after cholecystectomies. The higher incidence occurring with simple drainage of the gall bladder can be explained by the fact that the majority of the primary operations were performed in small rural hospitals or in charity institutions where the younger men were acquiring experience. It may be argued that the group submitting to cholecystostomy were too ill to undergo a more formidable operation, but such was not the case. Studies of their hospital records reveal that all these cases were scheduled for cholecystectomies, but conditions were encountered which compelled the "occasional operator" to employ simple drainage. Balfour and Ross estimate that 90 per cent of their 166 cases having biliary fistulas resulted from a failure to remove the gall bladder at the initial operation. They affirm that in performing a cholecystectomy the cystic and common bile ducts must be exposed, thus minimizing the possibility of overlooking a migratory stone. No one who cannot recognize and cope with choledochal lesions should attempt to operate for gall stones.

Surgical accidents such as, ligation, severance, and crushing of the common bile duct account for a small percentage of these fistulas. On 2 occasions the choledochus was accidentally clamped while the surgeon was attempting to control annoying hemorrhages. Inexperience, inadequate exposure, and speedy haphazard work propagate such errors.

Therapeutic external fistulas may be deliberately formed so as to decompress an obstructed biliary tree. For example, a cholemia may be so intense or the patient's condition so precarious that palliative drainage is imperative. Remedial operations are not employed until definite improvement has been made.

Short-circuiting procedures, such as cholecystoenterostomies, choledochoenterostomies, and hepaticoenterostomies are preferred to external drainage but unfortunately they cannot always be employed. In one instance we encountered such a generalized fibrosis of the choledochus and common hepatic duct that the formation of an external fistula afforded the only surcease from the intractable pruritis.

PREVENTION

An appreciation that 95 per cent of these external sinuses occur as unexpected complications following operations for gall stones emphasizes the importance of prevention. The observance of certain accepted surgical principles will greatly minimize the incidence of these tantalizing errors.

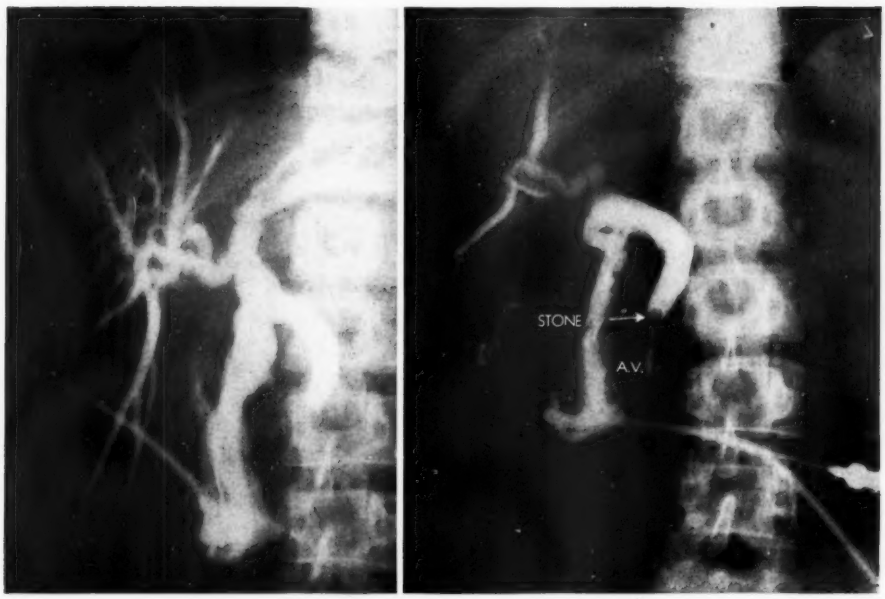
A. The importance of an accurate clinical diagnosis cannot be overestimated. It is not sufficient to know that the patient has gall stones but one should determine whether there may be a complicating cholangitis, acute cholecystitis, cholemia, or hepatic insufficiency. To be unexpectedly confronted by these serious complications may necessitate a simple cholecystostomy without being able to determine the functional status of the bile ducts. In 5 such instances the failure to recognize the presence of acute cholecystitis before operation necessitated conservative operations with the result that choledochal stones were not discovered and chronic fistulas resulted.

B. Adequate preoperative preparation and proper timing of all surgical interventions are absolutely essential in preventing such complications. The improperly prepared jaundiced patient is no candidate for exploration of the bile ducts. Likewise, the failure to provide ample time for acute infections to subside may necessitate palliative measures. For example, an acute cholecystitis usually responds to conservative therapy and extensive remedial operations can be safely employed during the quiescent phase which would be forbidden during the height of the inflammatory reaction. It is here that experience and judgment pay the highest returns.

C. It is obligatory that the functional status of the bile duct should be accurately determined before any type of extirpative surgery is undertaken. It has been our practice to explore the common bile duct if it contains stones, if it is dilated or indurated, if there has been an antecedent jaundice, if there is an inflammatory pancreatitis, and if unable to find other causes for the bilogenic dysfunctions.

Fig. 1. The gall bladder, cystic duct, choledochus and duodeum were all visualized by the introduction of 55 cubic centimeters of diodrast, 70 per cent, into the external sinus. Note the gall stones partially occluding the orifice of the cystic duct, thus interfering with the emptying of the gall bladder and accounting for the biliary fistula.

While these indications for choledochotomy are definite, unfortunately the recognition of their presence is a matter of individual interpretation. What is thought to be normal by one surgeon may be considered pathological by another. It is the border line case which gives us the most concern and provides the most fertile field for errors. Visual inspection and palpatory examinations often fail to detect the incomplete choledochal obstructions. Errors of omission can be entirely prevented by the employing of cholangiographic studies during the operation (5). If the bile ducts appear patent and the contrast fluid flows unhampered into the duodenum no further exploration is warranted. If, however, obstructive lesions are visualized, the proper remedial procedure can be employed. The diagnostic cholangiograms are accurate and give the surgeon a sense of security.



a b

Fig. 2. a, Postoperative cholangiogram reveals a dilated biliary tree with complete obstruction of the ampulla of Vater for the contrast media does not pass into the duodenum. b, Some 8 weeks later. The external decompression has permitted the pancreatitis to subside partially for the diodrast flows around the stone and escapes into the duodenum. Note the thread-like pattern of the ampulla of Vater which is indicative of pancreatitis. This patient was not jaundiced after operation, and the sinus healed spontaneously in spite of the choledochal stone.

D. External fistulas can be prevented if the postoperative studies detect provocative obstructions, thereby permitting immediate corrective therapy. Every patient submitting to a cholecystostomy or a choledochotomy should have a complete cholangiographic study before the drainage tubes are withdrawn (6). When the ducts appear patulous the drains can be removed with impunity. Should pathological obstructions be present they can be diagnosed by the recognition of their identifying characteristics. For example, gall stones cast incriminating "negative shadows" while blood clots and inspissated plugs of mucus produce pleomorphic "filling defects" which float around within the ducts (Fig. 1). Pancreatitis exerts a concentric compression of the ampulla of Vater so that when the contrast fluid passes through the narrowed ductal lumen it forms a distinctive thread-like pattern (Fig. 2). Carcinoma of the pancreas produces a slow, but progressive, obstruction of the ampulla of Vater resulting in a tremendous dilatation of all other segments of the biliary tract. Biliary dyssynergia is characterized by a temporary but complete obstruction of the terminal choledochus which spontaneously disappears as the spastic contractions of the sphincter of Oddi subside.

When the postoperative cholangiograms demonstrate a choledochal stone, attempts should be made to dislodge it by means of the biliary flush. Best and Hicken (2) have succeeded in washing residual calculi from the ducts into the intestinal tract, thereby obviating a second exploration. They suggest that the sphincter of Oddi be completely relaxed by the administration of nitroglycerine and atropine sulfate before the drainage tube and choledochus is lavaged with warm olive oil. By these ductal irrigations they "flushed 11 stones" from the common bile duct into the duodenum and recovered them in the feces (3). Butsch, McGowans, and Walters, follow-

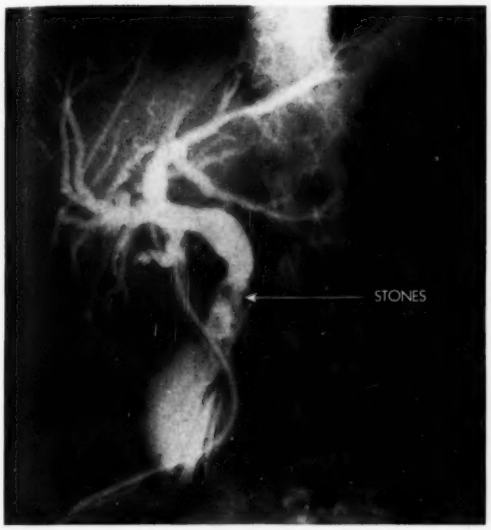


Fig. 3. This fistula closed 1 week after removal of the T tube in spite of choledochal stones. It is apparent that the calculi are not completely obstructing the duct. The rapidity with which the fistula healed, the absence of jaundice, and quick recovery of the patient gave no clinical signs of the overlooked stones; this emphasizes the value of cholangiograms.

Fig. 4. A woman, 76 years old, suffered from a perforation of an acute gangrenous gall bladder. A cholecystostomy with extraction of 2 large gall stones was performed. Deferred cholangiograms revealed an incarcerated ampullar stone which was overlooked at the primary operation. The resulting fistula healed spontaneously within 8 weeks in spite of the choledochal stone.

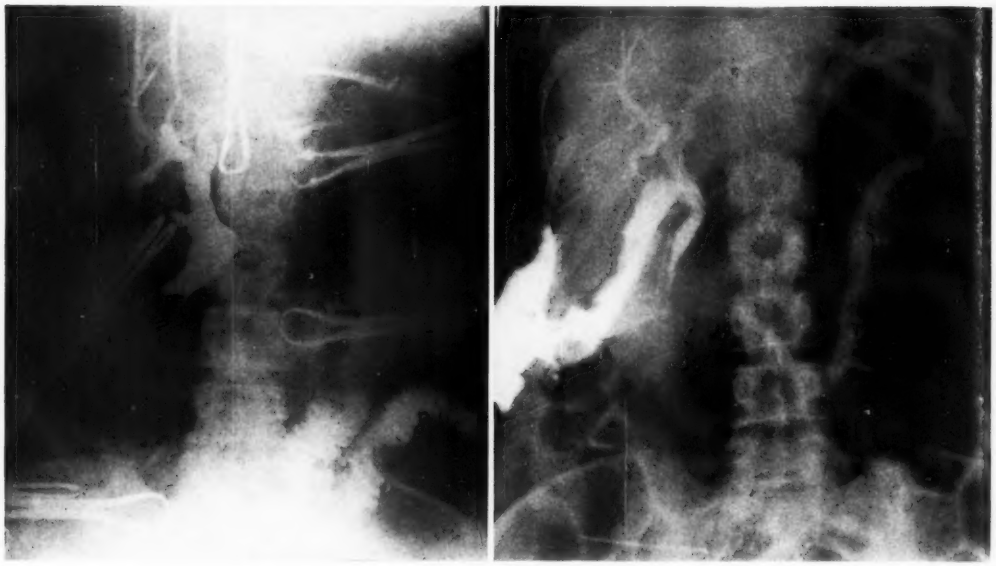
ing the suggestion of Pribram, dissolved the migratory stones by the intraductal instillations of ether. While both of these methods should be utilized before subsequent operations are resorted to, unfortunately they seldom accomplish the desired objectives. We have, however, been able to dissolve plugs of mucus and blood clots by irrigating the common bile duct with a solution of the essence of caroid.

If conservative procedures fail to remove the offending obstruction, operative intervention should be employed as soon as the patient's condition permits. It is unwise to wait for a permanent sinus to form, for fear that an ensuing cholangitis, hepatitis, cholemia, or hepatic insufficiency might complicate the problem.

CLINICAL FEATURES

It has been our experience that when the cholangiograms revealed the ducts to be patulous that all external drainage subsided within 5 days after the drainage tubes were with-

Fig. 5. Postoperative cholangiograms visualize choledochal stones that had been overlooked at the time of the primary operation. The patient was not jaundiced; the external sinus drained for 10 weeks, then it closed spontaneously in spite of the fact that ampullar stones were present.



a b

Fig. 6. a, Cholangiogram of a woman, 58 years of age, who had her gall bladder removed because it contained stones. The common bile duct was enormously dilated, but the operative cholangiograms demonstrated the choledochal obstruction to be due to a compressive occlusion of the ampulla of Vater by an inflamed pancreas. Note the thread-like shadow of the diodrast as it flows through the narrowed lumen of the ampulla. b, Postoperative cholangiograms which were taken 9 weeks later indicate that the pancreatitis has subsided, the choledochus is no longer dilated; the sinus tract closed just as soon as the T tube was removed.

drawn. Balfour and Ross maintain that if the drainage persists for more than 3 weeks, it is indicative of some pathological obstruction of the biliary tract. Apparently it requires a higher secretory pressure to force the bile out through a narrowed, tortuous fistula than along the normal ductal channels.

It is well to remember that the spontaneous closure of the fistula affords no assurance that the ducts do not harbor obstructive agents. It merely signifies that the obstruction is not complete. We have cholangiographic evidence in 4 cases showing that the external fistulas closed spontaneously in spite of the fact that their common bile ducts contained obstructing stones (Fig. 2). Apparently the prolonged external decompression permitted the cholangitis and pancreatitis to subside sufficiently for the bile to flow around the calculi and drain into the duodenum (Fig. 3). The accuracy of the cholangiograms was confirmed by subsequent operations (Fig. 4). These studies suggest that many of the so called "reformed stones" are merely "overlooked stones." (Fig. 5).

Jaundice was encountered in 21 per cent of the cases and was invariably associated with choledochal stones. One must remember, however, that 79 per cent gave no history of a preceding cholemia. Recurrent chills, fever, and toxic reactions occurred in 26 per cent and were the expressions of a suppurative cholangitis, pylephlebitis, hepatic and subhepatic abscesses.

The nature and character of the escaping discharge affords some index as to the site of the obstruction. An intermittent effusion of an acholic mucus is indicative of a complete occlusion of the cystic duct. If the mucus is bile stained and if the patient is not jaundiced, one suspects an intermittent obstruction of the cystic duct. When a copious quantity of a golden yellow bile flows continuously from the sinus it is pathognomonic of a choledochal obstruction (Fig. 6). If such a discharge should be intermittent it is indicative of a

"ball-valve action" of an ampullar stone. Mucopurulent bile is associated with a suppurative cholangitis.

TREATMENT

A well planned preoperative regimen for these handicapped patients is absolutely essential (10). All operative intervention should be postponed until the maximum rehabilitative responses have been made. We have discontinued the noisome habit of feeding the patients their own bile as it is frequently infected and is never well received. The use of bile salts, bile acids, and lyophilized bile readily compensate for the loss of this essential digestive fluid. Ravdin has convincingly demonstrated that the diet should contain 70 per cent carbohydrates, 25 per cent protein, and 5 per cent fats. Polyvalent vitamins are given to combat existing deficiencies. Hypoprothrombinemia can be readily corrected by the liberal use of vitamin K. Repeated transfusions of whole blood, blood plasma, and blood serum restore the cellular and other vital constituents of the blood to an approximately normal level. Rapid improvement usually follows the use of this physiological therapy.

The presence of jaundice or of a suppurative cholangitis indicates that the external fistula is not providing adequate drainage of the obstructed biliary tree. Studies indicate that the fistulous tract tends to become strictured, either where it penetrates the muscular and fascial portion of the anterior parietes or at its cutaneous orifice (Fig. 7). On 2 occasions cholangiograms have visualized large subcutaneous pockets of infected bile caused by a calcerous obstruction of the ampulla of Vater and a cicatricial narrowing of the external sinus. Adequate drainage was obtained by incising the cutaneous orifice of the fistula thus liberating the static bile. Within a period of 10 days, all signs of cholemia and cholangitis had subsided and the choledochal stones were removed. In another patient 2 small stones were removed from the outer segment of the fistulous tract, thereby providing ample drainage.

Complete cholangiographic studies should be made the day preceding the operation by the injection of a suitable contrast fluid into the sinus tract[1]. By visualizing the location and determining the extent of the obstructive lesion, the surgeon can more wisely plan his remedial attack. These preoperative cholangiograms are just as essential to the biliary surgeon as urograms are to the urologist.

Fig. 7. The cholangiogram outlines a large subcutaneous pocket of infected bile. Note that the sinus becomes narrow where it penetrates the fascial wall, *A*, and at its cutaneous orifice, *B*. By incision and dilatation of the external opening the infected bile was evacuated, the cholemia disappeared, and subsequent cholangiograms demonstrated the presence of stones of the ampulla. These were removed.

When the fistula connects with the gall bladder, the latter should not be disturbed until the functional status of the bile ducts has been established. Occasionally the cystic duct will be occluded, in which event the preoperative cholangiograms will fail to outline the common bile duct. In such cases, it becomes necessary to explore the choledochus by means of operative cholangiograms. This is accomplished by the insertion of a No. 22 gauge needle into the choledochal lumen and the introduction of from 15 to 50 cubic centimeters of diodrast (70 per cent). If these visualizing cholangiograms demonstrate the ducts to be patent, and, if the diodrast flows uninterruptedly into the duodenum, no further explorations are required. A simple cholecystectomy with excision of the fistulous

[1] Diodrast—70 per cent by weight-volume.

tract will prove curative. If obstructive lesions are seen within the ducts, the offending impediments are removed.

In cholecystectomized patients, the external sinus is not molested until the common bile duct has been explored either surgically or roentgenographically. The perisinous adhesions can be avoided if the peritoneal cavity is entered mesial to the fistulous tract. This permits the stomach and duodenum to be mobilized, thus affording an excellent exposure of the choledochus. As the stones have been previously localized by cholangiographic studies, no difficulty is encountered in their removal. In case of an irreparable stricture or an obstructive carcinoma, some type of plastic operation is required to shunt the static bile into the gastrointestinal tract. Whenever possible a choledochoenterostomy or a hepaticoenterostomy should be performed as they provide better drainage than does the transplantation of the external sinus tract (7). In 1 instance we were compelled to transplant the fistula so that it communicated with the duodenum. Fortunately, a most pleasing recovery resulted, and the patient is doing well 3 years later.

In the removal of choledochal stones the following points of surgical technique should be observed: (1) Never crush a stone in order to expedite its extraction as it is impossible to remove the fragments. Residual fragments invariably form recurrent stones. Stone grasping forceps are used when a firm calculus is to be manipulated whereas the scoops are more effective when the soft, pultaceous variety of stone is extracted. (2) Incarcerated ampullar stones are sometimes more easily removed by transduodenal choledochotomy than through the convention route. (3) Mobilization and rotation of the duodenum medially may provide direct access to large stones imprisoned in the retroduodenal segment of the common bile duct. This approach is contraindicated if there is a coexisting pancreatitis. (4) Thorough mechanical irrigations of the bile ducts with a solution of warm saline will frequently dislodge and flush out small calculi, biliary sand, and plugs of amorphous detritus which might otherwise be overlooked.

Whenever the common bile duct is opened or explored T tube drainage is employed. The size of the T tube should be such that it will provide adequate drainage and yet small enough so that the walls of the incised duct can be reunited around it. The approximating suture line should be water tight in order to prevent the extravasation of bile. This can be determined by irrigation of the T tube with a solution of saline. If the fluid regurgitates around the catheter it means that the suture line is not secure or that there are some obstructive lesions preventing the fluid from escaping into the duodenum. In this event a second operative cholangiogram is made after the introduction of diodrast 70 per cent, directly into the T tube. If obstructive lesions are visualized, the T tube is removed and remedial measures are immediately employed. If such a plan is properly executed, it precludes the possibility of overlooking choledochal stones.

A correct postoperative regimen will greatly minimize the untoward hepatic reactions which all too frequently follow these surgical insults. All patients receive continuous oxygen therapy during the first 72 hours. Such therapy has greatly reduced the incidence of pulmonary complications and lessened the dangers of cardiac failure. This is particularly true in the cholemic patient as their damaged livers are unable to elaborate a normal hemoglobin and unless they receive an abundant supply of oxygen a detrimental anoxemia may develop. Hepatic insufficiency and liver shock are best combatted by administering vitamin B complex and nicotinic acid in liberal amounts and by the use of a continuous intravenous drip of a solution of 5 per cent glucose. If there is a cholorrhea particular attention must be given to the electrolytes of the blood, for these patients lose enormous quantities of chlorides and bases. The nausea and vomiting can best be controlled by decompressive intestinal intubation.

It is imperative that the choledochal drainage tubes be kept open so as to decompress the engorged liver. At times the emitting discharge may be so viscid that it will not flow from the catheter, and, unless the tube is frequently irrigated with a solution of warm

saline, it may become clogged. Likewise, if the secretions are mucoid or hemorrhagic they tend to obstruct the tube and inhibit free drainage. This can be prevented by filling the T tube with a solution of the essence of caroid which liquefies the clots and dissolves the mucus. As soon as bile is detected in the stools, the drainage tube can be clamped so as to force this essential secretion into the duodenum. If the flow of bile is sluggish the administration of dehydrocholic acid acts as a cholagogue thus producing an effective physiological biliary flush. Should there be a spastic contraction of the sphincter of Oddi, this may be supplemented by the use of nitroglycerine and atropine sulfate.

How long shall the common bile duct be drained? Cholangiography affords the only accurate answer to this question. When the cholangiograms demonstrate the bile ducts to be patent then the drainage tubes can be safely removed. Should there be a residual pancreatitis or cholangitis, the external drainage must be continued until these inflammatory reactions have subsided (Fig. 7).

RESULTS

Twenty-three patients with external biliary fistulas underwent 28 separate operations with a mortality rate of 26 per cent. It was interesting to note that in 16 private cases there was but 1 death, 6 per cent. This does not mean that the charity patient does not receive the same conscientious treatment as the private client but rather that the former neglect to seek early therapy because of economic embarrassment.

An analysis of the causes of death emphasizes the dangers of late complications. One patient, having had a fistula for 11½ years and persisting jaundice for 6 months, died because of hepatic shock incidental to an extensive cirrhosis. Carcinoma of the liver proved fatal to 1 woman who had suffered with a draining sinus for 36 months. Postoperative hemorrhage accounted for 1 death but this was before vitamin K therapy was fully understood. Pylephlebitis, biliary peritonitis, hepatic, subhepatic, and subphrenic abscesses likewise exacted their toll. It is evident that the majority of these complications could have been prevented by timely surgery.

SUMMARY

1. Twenty-three cases of persistent external biliary fistulas are presented with particular reference to etiology, prevention, diagnosis, and treatment.

2. Ninety-five per cent of these fistulas occurred as complications following cholecystostomy and cholecystectomy.

3. The failure to remove all the gall stones at the primary operation accounted for 88 per cent of the fistulas.

4. The indications for and the technique of preoperative, operative, and postoperative cholangiography are presented.

5. The diagnostic and therapeutic value of cholangiograms is emphasized by case presentations.

6. The surgical and postoperative management of the various types of biliary fistulas is given.

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TESTICULAR BIOPSY
FURTHER STUDIES IN MALE INFERTILITY

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IN 1940, one (2) of us reported studies on testicular biopsy and its application in the diagnosis of male infertility. This procedure consists of the removal of a minute piece of tissue from the periphery of the testis through a small incision in the scrotum. It is a simple innocuous procedure and may be performed in the office under local anesthesia. In our experience there have been no undesirable after-effects, every patient resuming his usual activity the next day.

While the performance of biopsy was at first limited to instances of azoospermia, it soon occurred to us that this procedure could be utilized in patients with any type of spermatozoan deficiency, whether it be morphological or numerical. The more biopsies performed, the better we appreciated the superiority of this method over any other procedures. The two older methods available today are aspiration of the testis and the manifold biological studies of the ejaculate. Testicular aspiration, even when spermatozoa are obtained, gives merely quantitative data and is valuable only in the differential diagnosis between obstructive and nonobstructive azoospermia. In the study of the ejaculate the finding of a large percentage of abnormally formed spermatozoa points only to faulty spermatogenesis. Both these older methods, however, fail to give information regarding the nature of the intrinsic lesion in the seminiferous tubules. The insight into actual pathogenesis, as revealed by testicular biopsy, is in our opinion, the *sine qua non* in a thorough study of male infertility.

The present series of testicular biopsies, performed as part of the study on males with reduced fertility, numbers 95. This series comprises a variety of pathological types, including instances of both testicular underdevelopment resulting from a congenital endocrine imbalance and testicular degeneration of a normally developed testis brought about by inflammation, toxic processes, or post-pubertal endocrine disturbances. An analysis of the findings indicates that these two lesions can be differentiated by the data obtained through testicular biopsy, and that this differentiation, as will be shown, is of utmost importance in determining the prognosis and type of treatment. Lest the objection be raised that the tissue obtained through biopsy may not necessarily be representative of the entire gland, it should be pointed out that large sections of normal testis obtained at autopsy done immediately after death show a general uniformity of the seminiferous tubules (Fig. 1) and also that sections of biopsies from different portions of the same testis obtained at intervals of 6 weeks show similar pathological processes throughout.

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THE NORMAL SEMINIFEROUS TUBULE

A cross section of a testis shows two distinctly different types of tissue: the seminiferous tubules, in which spermatogenesis takes place, and the interstitial tissue, which contains the cells of Leydig. In the seminiferous tubules the successive phases of spermatogenesis are arranged according to a definite sequence. The youngest and least developed cells are situated on the basement membrane of the tubule, the membrana propria, while the mature forms are more centrally located. Accordingly, the spermatogonia, the cells in which spermatogenesis begins, and the next generation, the primary spermatocytes, remain in their early growth phases adjacent to the basement membrane. Advancing toward the center the primary and secondary spermatocytes are seen undergoing division and further development. The next layer of cells is composed of groups of sperma-

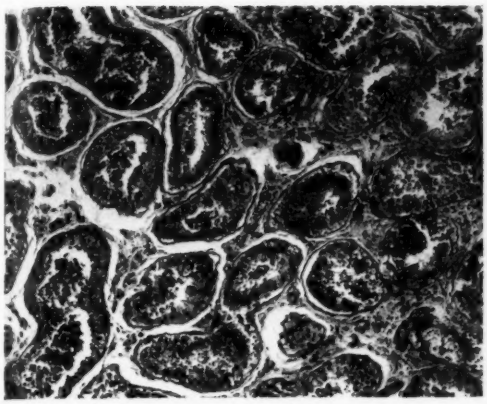

Fig. 1. Typical portion of testis, removed at autopsy immediately after death, illustrating uniformity of tubules (× 60). (Formalin fixed.)

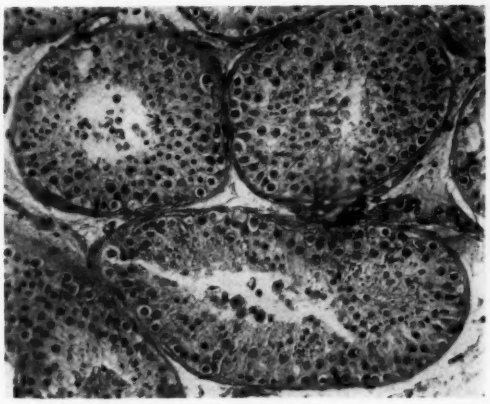

Fig. 2. Normal seminiferous tubules. Note presence and regular arrangement of various generations of spermatogenic cells. Membrana propria of normal thickness. (× 150.)

tids. Finally and innermost, one sees groups of immature spermatozoa (Fig. 2).

In addition to these spermatogenic elements, the seminiferous tubule shows another type of cell, the so called cells of Sertoli. These are slender, columnar elements standing upright on the basement membrane and spaced at fairly regular intervals. They are presumably supporting elements, though some consider them capable of developing, under certain conditions, into true spermatogenic cells.

The wall of the seminiferous tubules, the membrana propria, consists of thin collagenous fibers and a delicate elastic network, and varies in thickness from 3 to 6 microns. The interstitial tissue—the tissue between the tubules—consists of thin collagenous fibers, blood and lymph vessels, nerves, and several varieties of cells—fibroblasts, resting wandering cells, mast cells, embryonic perivascular cells, and the interstitial cells of Leydig which are believed to elaborate the internal secretion of the testis.

Occasionally one notes seminiferous tubules showing degenerating spermatogenic cells involving all generations, particularly spermatocytes and spermatids. Such degenerating cells lose their connection with the rest of the epithelium, are cast off into the lumen, and disintegrate into granular and fatty débris. Tubules exhibiting such degenerative changes, if not excessive, need not be considered pathological, especially if they are surrounded by tubules with normal spermatogenesis in full progress.

THE PATHOLOGICAL SEMINIFEROUS TUBULE

Careful study of the 95 testicular biopsies herein reported revealed that the pathological changes, although varying considerably in degree, could be separated into two distinct types: (1) intratubular—those in which the degenerative or developmental lesion is confined solely to the seminiferous tubules; and (2) peritubular—those in which peritubular fibrosis, either inflammatory or replacement, is seen in addition to the intratubular lesion.

Of the 95 biopsies 16 showed normal spermatogenesis. Of the 79 remaining, 51, or 65 per cent, showed moderate to marked peritubular fibrosis, while only 28, or 35 per cent, showed a normal amount of peritubular connective tissue despite definite damage to the tubular epithelium.

Type I. Intratubular lesions. The pathological changes confined to the tubules have been found to vary in severity from simple desquamation of the innermost layer of cells, the spermatids, to more severe degenerative changes in which both the spermatocytes and spermatogonia are involved or, finally, to a stage in which the tubule consists of merely a single layer of undifferentiated cells appar-

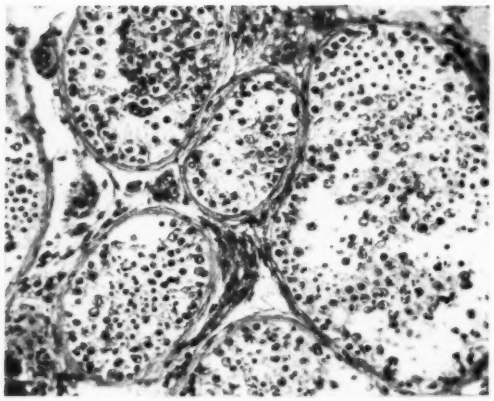

Fig. 3. Case 1. Section of testis, before treatment, showing mostly disorganization and incomplete epithelial differentiation. Only the large tubule appears capable of producing spermatozoa. No peritubular fibrosis. (× 250.)

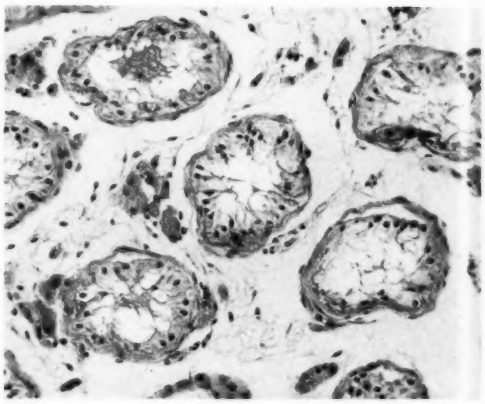

Fig. 4. Case 2. Section from surgically corrected cryptorchid testis showing atrophic tubules lined by a single layer of undifferentiated cells. No peritubular fibrosis. (× 150.)

ently incapable of growth and division. In the milder cases, the younger cell forms are not affected and differentiation into spermatids continues. Under such circumstances, further cell growth is interrupted and a testicular biopsy reveals an increase in the number of spermatids. In the more severe forms, desquamation is more prominent, a great deal of débris often being seen in the lumen, and the tubule is lined with only one or two layers of cells.

Whatever the etiological factors may be, the intratubular degenerative process may be halted at any point and, since the basal layer of cells, the spermatogonia, has not been affected, regeneration may take place under suitable circumstances. Thus, if the disturbing factor be a pituitary deficiency, restoration to normal could be effected by the administration of a pituitary gonadotropic substance.

The 4 cases cited are selected from a group of 28 showing intratubular damage only. Of these 28, improvement in the semen picture or biopsy or both, followed the administration of equine gonadotropin in 11 instances. These 11 cases, we believe are patients with mild insufficiency of pituitary gonadotropin. The 17 remaining cases probably represent either testicular lesions of nonendocrine etiology or are instances of endocrine deficiency so advanced that regeneration following treatment with the gonadotropins at present available has not occurred.

Case 1. Mild degree of tubular damage without fibrosis. G. C., aged 29 years, had a moderate amount of girdle obesity. Basal metabolic rate was −8. Semen examination revealed a total count of 9,000,000 spermatozoa, of which 38 per cent were morphologically abnormal. Following the administration of an equine gonadotropin, the total sperm count was raised to 80,000,000 with only 29 per cent abnormal forms and with a corresponding improvement in the histological picture (Fig. 3).

Case 2. Severe tubular damage without fibrosis. F. L., aged 28 years. This was an instance of underdevelopment in a man with cryptorchidism which had been surgically corrected at the age of 25 years. The testes averaged 3.5 by 2.0 centimeters in size. Semen examination showed azoospermia. There was no response to the administration of equine gonadotropin (Fig. 4).

Case 3. Acute tubular degeneration without fibrosis.[1] F. S., aged 25 years, had been given 5 milligrams of stilbestrol daily for a total of 480 milligrams in order to suppress his hypersexualism which had earned him repeated incarcerations for criminal rape. His testes were reduced to two-thirds of their original size and his libido was so suppressed that a semen specimen could not be obtained. It is important to note that during this period of testicular degeneration, he had no symptoms referable to the testes (Fig. 5). Two months following the cessation of therapy, a second biopsy showed very pronounced evidence of regeneration. Libido had returned to normal (Fig. 6).

[1]This instance of stilbestrol-induced degeneration is being reported in greater detail by Dr. C. W. Dunn.

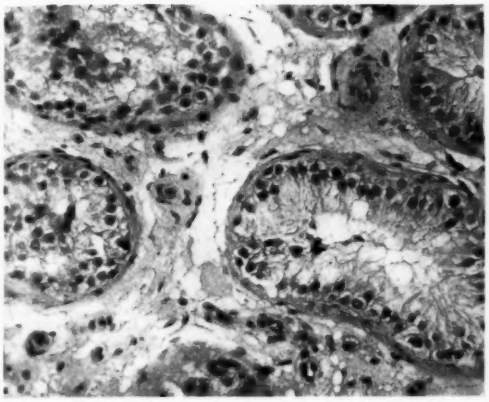

Fig. 5. Case 3. Section from stilbestrol-induced degeneration. Tubules are lined by only one or two layers of healthy cells and display central necrosis. Note interstitial edema and absence of peritubular fibrosis. (× 150.)

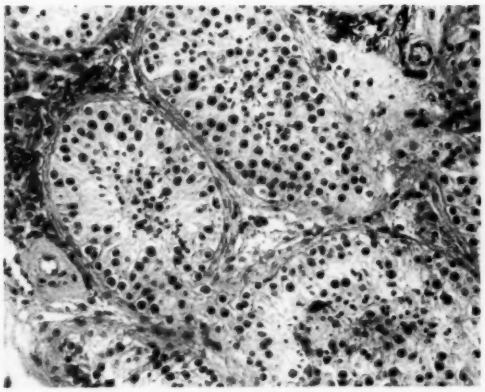

Fig. 6. Case 3. Section from same patient as in Figure 5, 2 months after cessation of stilbestrol, showing restoration. Regenerative process proceeding, but not yet complete. Note focal fibrosis. (× 150.)

Case 4. Tubular underdevelopment and degeneration without fibrosis. S. G., aged 29 years, displayed many of the stigmas of hypogonadism. He shaved his beard once a week. He had trochanteric obesity, with a prominence of the breasts and abdominal fat. The penis was small; the testes measured 2.5 by 1.5 centimeters. Semen examination revealed azoospermia (Fig. 7). He received intramuscular injections consisting of 40 milligrams of testosterone proprionate and 120 international units of equine gonadotropin weekly for a period of 4 months. Re-examination revealed no change in size of testes, an increase in size of penis, with normal libido and potentia. There was no improvement in the semen (Fig. 8).

Type II. Peritubular fibrosis. The presence of peritubular fibrosis is indicative of either the end stage of an inflammatory process or of a severe degenerative process which has produced, in addition to epithelial damage, an infolding and thickening of the membrana propria, a shrinkage of the tubules, and subsequently replacement fibrosis. Such peri-

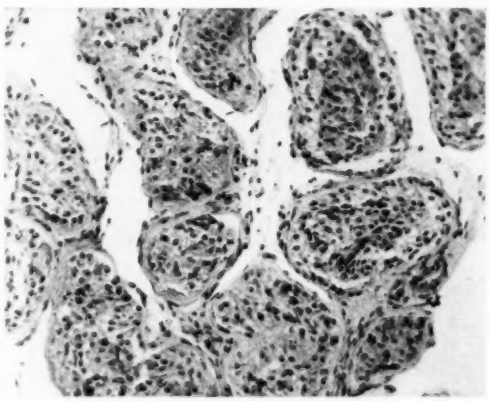

Fig. 7. Case 4. Section from patient with hypogonadism. Marked underdevelopment. Note small size of tubules. No peritubular fibrosis. (× 150.)

(This tissue was fixed with formalin.) All other tissues, except that used in Figure 1, were fixed with a modified ("B₂"-McClung) Bouin's solution.

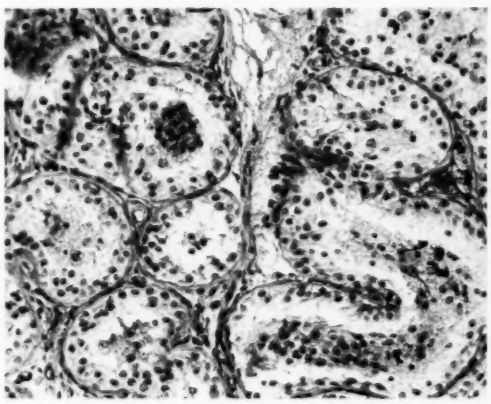

Fig. 8. Case 4. Section from testis of hypogonad after treatment with testosterone proprionate. No increase in size of tubules or in the number of epithelial layers. Note appearance of necrosis and its similarity to stilbestrol-induced necrosis of Figure 5. (× 150.)

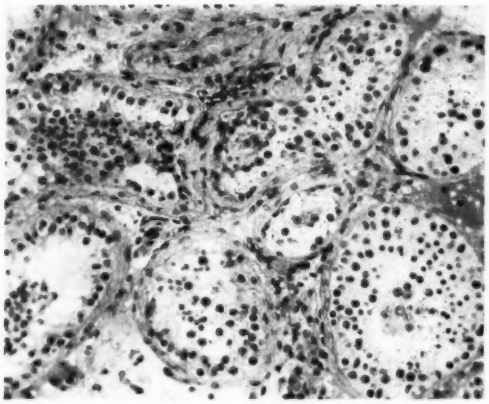

Fig. 9. Case 5. Section from testis showing degeneration following upon an inflammatory process. Note small degenerated tubules, thickening of membrana propria, and peritubular fibrous tissue. (× 150.)

tubular fibrosis must not be confused with the apparent increase in the number of interstitial cells of Leydig—a phenomenon caused by a relative reduction in the size of the tubules. The importance of this peritubular fibrosis is that it signifies an accompanying involvement of the membrana propria adjacent to the mother cells, the spermatogonia, and implies previous injury to them. The degree of peritubular fibrosis varies from a simple thickening of the membrana propria to instances in which the fibrous ring is as thick as the tubule itself. In the most advanced cases, fibrosis is represented by actual scarring with complete obliteration of the tubules.

It is of the utmost importance to note that not one of the patients with peritubular fibrosis, even of the mildest degree, responded to the administration of equine gonadotropin. The 2 cases cited are selected from a group of 51, showing tubular damage associated with varying degrees of peritubular fibrosis.

Case 5. Mild tubular damage associated with generalized peritubular fibrosis. D. L., aged 28 years, showed no evidence of endocrine disturbance. He gave no history of pain or swelling of the testes which were normal to palpation. Total sperm count was 6,000,000 with 42 per cent abnormal forms. In addition to the microscopic picture, there was also gross evidence of previous inflammation of the testes. At biopsy the fascial layers of the scrotum, particularly the parietal layer of the tunica vaginalis testis, were thickened, and there was an excess of hydrocele fluid present. The administration of equine gonadotropin failed to produce any change in the semen picture (Fig. 9).

Case 6. Severe tubular damage accompanied by generalized peritubular fibrosis and partial obliteration. A. L., aged 25 years, exhibited marked familial, evenly distributed obesity. He gave no history of testicular disease. Basal metabolic rate was −4. Roentgenogram of sella turcica was normal. The right testis was normal, the left definitely reduced in size. During the performance of testicular biopsy, gross evidence of previous inflammation was apparent. On the left side, the two layers of the tunica vaginalis testis were adherent. Semen examination revealed a total of 9,000,000 spermatozoa with 58 per cent abnormal forms, which undoubtedly originated in the right testis. Treatment with equine gonadotropin failed to produce any change in the semen (Fig. 10).

CORRELATION OF TESTICULAR BIOPSY AND SEMEN STUDY

The correlation of the semen findings and the histological pattern of the biopsy was as follows:

Of 76 patients with oligozoospermia, the biopsy and semen specimen examinations agreed in 66 or 87 per cent; of the 19 patients with azoospermia, the biopsy and semen specimen examinations agreed in 13 or 68 per cent. In the group with oligozoospermia, the discrepancy in 13 per cent of the cases does not represent a percentage of error in the interpretation of the biopsy or semen findings. These cases, we believe, are instances of oligozoospermia with normal spermatogenesis in whom the lesion is confined to the ejaculatory ducts and is obstructive in nature. They are always associated with prostatic and seminal vesicular infection. The semen is reduced in volume, contains a large number of pus cells, and the spermatozoa display relatively normal morphology. In the group with azoospermia the disagreement in 32 per cent is, of course, confined to those cases in which spermatogenesis is normal and in which the obstructive lesion, in most cases, is more apparent. Of the 6 cases, 4 had bilateral obstruction of the epididymis and 2 had complete obstruction of the ejaculatory ducts with aspermia.

EVALUATION

When this study was begun, it was hoped that a careful analysis of the testicular biop-

sies would lead to a correlation between histological findings and specific etiological factors. It soon became apparent, however, that the pathological changes observed in the biopsies had no specific relation to the causative agent. It was found, moreover, that the presence or absence of peritubular fibrosis was a most valuable differentiating finding. Thus, no fibrosis was found in any of the clinical entities associated with underdevelopment of the testes, such as in the pituitary-gonadal deficiencies, in primary hypogonadism, and in cryptorchidism. Such testes uniformly showed tubules smaller in size than normal and lined by incompletely developed or undifferentiated epithelial elements. On the other hand, the acquired degenerative lesions, such as those due to toxins, inflammations or postpubertal endocrine disturbances, almost invariably showed some degree of peritubular fibrosis. The only exceptions apparently occurred in the mild cases of tubular degeneration, and in the very acute instances which did not, therefore, represent end stages. An example of the latter is the injury produced by stilbestrol (Case 3). Such cases are especially interesting in that they illustrate clearly the regenerative potentialities of the testes, when the toxic agent is removed or a stimulating remedy is introduced. The authors believe that if the stilbestrol had been administered over a sufficiently long period of time, tubular damage would have become so extensive that shrinkage would have occurred, generalized replacement fibrosis would have set in and regeneration would have been much less in evidence. As a matter of fact some parts of the section showed areas of focal fibrosis.

The evidences of tubular degeneration induced by the administration of both stilbestrol and testosterone proprionate in our cases are fairly conclusive. It is clinical confirmation of the findings of several investigators who demonstrated tubular degeneration following the administration of a variety of androgens in the experimental animal. It is especially significant that in our case the testosterone proprionate produced degeneration of the seminiferous tubules in a hypogonad, one in whom male sex hormone therapy is indicated according to our present concepts.

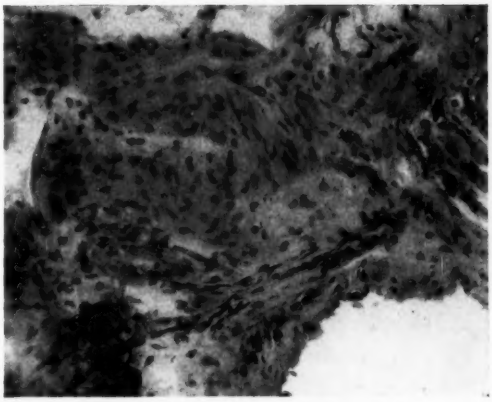

Fig. 10. Case 6. Section from left testis showing destruction of tubules with replacement fibrosis. (× 150.)

One point that deserves re-emphasis is that the pathological process in any testis is fairly uniform throughout and that a small specimen removed at biopsy is almost invariably representative of the entire testis. It is not uncommon, however, to find different degrees of involvement in the two testes even though the etiological agent is identical in each case. An example of this is the patient in Case 6, in whom the left testis was almost completely fibrosed, as demonstrated by biopsy, while the right one was severely and irreparably damaged by fibrosis of similar etiology but was still sufficiently spared to produce the spermatozoa found in the semen. It is interesting to note, however, that this patient's semen contained 58 per cent abnormally shaped spermatozoa.

It has not been sufficiently stressed that the majority of males with reduced fertility who are almost routinely treated with some type of endocrine product, do not show any clinical evidence of endocrine disturbance. Nor do these patients show any evidences of endocrinopathy when studied by the available laboratory procedures, such as basal metabolic rate, roentgenogram of the sella turcica, and urinary and blood levels of androgens and gonadotropins. There is, moreover, no logical justification for concluding that these patients have an isolated endocrine dysfunction of the seminiferous tubules. The observations in the present series of 95 testicular biopsies lend

additional support to the contention that the great majority of these testicular lesions are degenerative and are, for the most part, due to local or distant inflammatory or toxic processes. Since no endocrine imbalance exists, such seminiferous tubules cannot be expected to respond to endocrine therapy.

It is not possible at the present time to determine the specific etiology of the lesions in the seminiferous tubules. Since most of the inflammatory and degenerative changes occur insidiously, the characteristic signs and symptoms of inflammation are lacking and the patient usually gives no history of such a complication (see Case 3). It may be pointed out, moreover, that these nonendocrine degenerative changes have been recognized before in autopsy material and have been reported upon by a considerable number of investigators. Berberich and Jaffe report degenerative lesions involving the seminiferous tubules in a large percentage of men who contracted a great variety of acute infections. Oberdorfer reports degeneration of seminiferous tubules in every German soldier dying of influenza in 1918 whom he examined at autopsy. He stresses an important concept with which we are in complete agreement, namely, that almost all inflammatory lesions involving the seminiferous tubules begin in the epithelial structure of the tubules and that the peritubular fibrosis, though prominent, is always secondary and indicates epithelial damage as well. A large variety of diseases may produce hematogenous lesions. Some of these provocative ailments are typhoid, paratyphoid, mumps, diphtheria, scarlet fever, variola, influenza, typhus fever, tonsillitis, glanders, pneumonia, malaria, gout, rheumatic fever, furunculosis, osteomyelitis, cholecystitis, appendicitis, and localized focal infections with pyogenic organisms.

SUMMARY AND CONCLUSIONS

1. Testicular biopsy is an innocuous procedure, no more disabling than a Rubin test in the female, and should be established as a routine procedure in the study of male infertility.

2. The failure of tubular development is indicated histologically by the presence of small tubules which are filled with undifferentiated cell forms. Peritubular fibrosis is not present.

3. Degenerative lesions, if acute, are recognized in testicular biopsies by the presence of necrosis and desquamation of the tubular epithelium. If the lesions are of long standing, peritubular fibrosis is a distinct feature and signalizes either the end stage of an inflammatory process or the replacement fibrosis which results as a consequence of shrinkage of the tubules.

4. The presence of peritubular fibrosis suggests severe damage to the youngest epithelial cells of the tubules, probably affecting their regenerative potentialities.

5. The administration of sex hormones, either stilbestrol or testosterone proprionate, induces tubular degeneration both in the hypersexual male and in the hypogonad.

6. The majority of male patients with relative infertility have no endocrine disturbances. Their semen deficiencies are the result of degenerative lesions of the seminiferous tubules caused by either regional or constitutional inflammatory or toxic processes. Endocrine therapy is not indicated in such instances.

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SOME MODIFICATIONS ON THE ASEPTIC DOUBLE VALVED TUBOGASTROSTOMY

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SINCE the publication of a former paper entitled "A New Aseptic Double-Valved Tubogastrostomy" I have had many opportunities to observe and to study the technique employed by various surgeons who have been kind enough to try this method. Often it was noted that, when placing the pursestring suture around the base of the diverticulum which was formed by traction on the anterior wall of the stomach, the operator attempted to make a perfect circle. In other instances the surgeon needlessly ligated gastric vessels and cut into the gastrocolic ligament to mobilize part of the greater curvature and even the posterior wall of the stomach so as to achieve such a circular pursestring suture in the seromuscular layer. Indeed, the diagrammatic sketch in my earlier paper did illustrate a circular stitch, but I have since learned by further experience that an irregular circular or even an oval shaped pursestring suture, when tensed finally to the proper degree of constriction, forms a diverticulum which is entirely satisfactory. This modification of my method, made possible because of the elasticity of the stomach wall, eliminates the necessity of infringing upon the gastric vessels at the greater and lesser curvatures. Before the second pursestring suture is applied in the creation of this diverticulum, the Babcock forceps is released and reapplied to the point selected as the final apex.

It is obvious that when the operator tenses the pursestring suture, the stomach wall nearest to the sliding knot suffers the greatest amount of tension and constriction. This is avoided by introducing a pursestring suture which is "back stitched" after every fourth stitch is tensed, until the base of the diverticulum is completely encircled. This precaution imparts relatively equal tension and constriction to all points and prevents undue crushing at any one point.

Numerous requests have been received by me to explain why I chose to include 2 valves in the tubogastrostomy. During the development of the technique it was found that food settling along the greater curvature and exerting a downward pull rendered the first valve slightly incompetent. Therefore, a second valve was introduced, distal to the first, and was found to be unaffected by the weight of the feeding. However, in those instances in which there is not enough stomach wall to make a diverticulum that would permit the formation of 2 valves, a method which includes but one valve has been developed and tried by me and it has proved competent in preventing leakage of the gastric content, both in animal experiments and on human subjects. The technique of producing an aseptic tubogastrostomy with such a single valve is as follows:

1. With a Babcock forceps, traction is applied upward until the stomach wall is converted into a cone shaped diverticulum.

2. A pursestring suture—of braided silk, or No. 2 chromic catgut—is carried through the seromuscular layer at the base of the diverticulum in the manner indicated in Figure 1, A.

3. The Babcock forceps is released and reapplied to a final apical point on the diverticulum, and a second re-enforcing pursestring suture is inserted about 4 millimeters above the first (Fig. 1, B). (In a personal communication, L. Aries suggested placing the second pursestring suture midway between the first and third).

4. Then a third pursestring suture is inserted about 1 centimeter above or peripheral to the second.

5. Lembert stitches are now placed in the seromuscular layer at right angles to all pursestring sutures (Fig. 1, C) in sufficient numbers to encircle adequately the base of the partially constricted divertiuclum. The Lembert stitch employed here is somewhat modified; that is, the suture is inserted about 8 millimeters below the first pursestring and carried to a point about 1.5 centimeters beyond the second.

6. Interrupted seromuscular sutures are inserted in the anterior wall of the stomach at points superior, inferior, and lateral to the base of the tubal projection in order to fix the stomach wall to the peritoneum and posterior rectus sheath (Figs. 2, D and E). In a similar manner the tube itself is attached to the anterior rectus sheath.

7. An opening into the apex of the tube by means of cautery may be made any time from the

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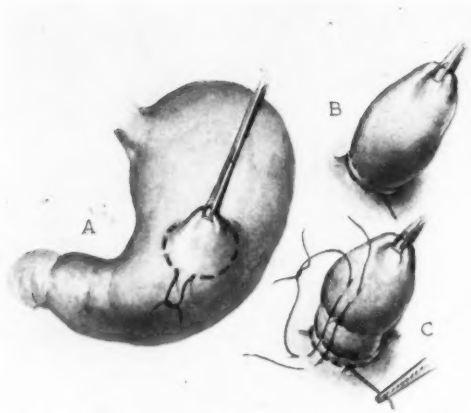

Fig. 1. A, Formation of a cone shaped diverticulum from the anterior wall of the stomach by upward traction with a Babcock forceps. B, Fixation of the formed diverticulum by 2 basal pursestring sutures. C, Insertion of a third pursestring suture about 1 centimeter above or peripheral to the second. Lembert stitches are placed in seromuscular layer at right angles to pursestring sutures.

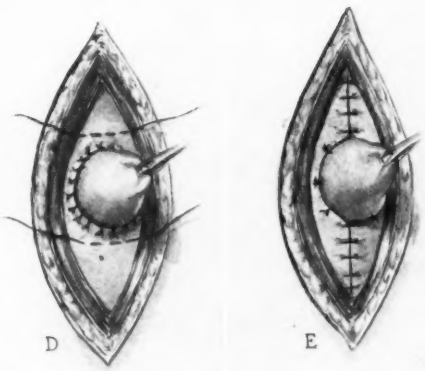

Fig. 2. D, Anchoring the anterior stomach wall to the peritoneum and posterior rectus sheath. E, The diverticulum protruding through the opening during the closure of the peritoneum and posterior rectus sheath. Additional interrupted silk sutures are shown anchoring the lateral sides of the stomach to the peritoneum and posterior rectus sheath.

first to the tenth day after the completion of the the operation (Fig. 3, G). It has been found more desirable to delay the opening as long as possible, depending upon the patient's ability to swallow liquid food, since a greater time is allotted for adhesions to form and for edema to disappear. This step culminates an operative procedure that requires a minimum of time and trauma and that is aseptic throughout.

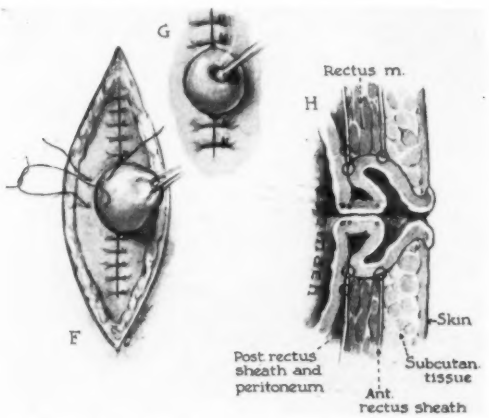

Fig. 3. F, Two untied sutures are shown anchoring the tube proper to the anterior rectus sheath. Interrupted silk sutures are employed to close the split anterior rectus sheath. G, Illustrates a cautery applied to the apex of the tube. It is the final step of the operation procedure, and is best carried out several days after operation. H, Diagrammatic cross section illustrating the broad tubular approximation of the basal valve. The circles represent suture ties employed throughout the operative procedure.

In Figure 3, H, a diagrammatic cross section illustrates the arrangement of the various layers of the stomach wall after the invagination resulting from the three pursestrings has been completed. It will be noted that while the modified Lembert suture invaginates the three pursestring sutures, it also produces a more abundant overlapping of mucosal folds within the tubal structure which are more than adequate in maintaining a competent closure. Although the gastrostomy possessing only one valve has proved competent and is preferred by O'Donoghue, Aries, and others, I still favor my original double valved tubogastrostomy whenever an adequate amount of stomach wall is present.

At this point I would like to add a few remarks regarding the selection of the ideal site of the gastrostomy. In cases of carcinoma of the upper or the middle third of the esophagus, the operator may proceed to perform a gastrostomy in any available portion of the anterior wall of the stomach. But in cases in which the malignancy involves the lower third of the esophagus or the cardiac portion of the stomach, the writer prefers to utilize that portion of the anterior stomach wall

farthest from the site of lesion, that is, as far from the cardia as possible without encroaching upon the pylorus. The rationale guiding here is based on the assumption that the farther removed the gastrostomy site is from the malignancy, the longer it will take for the cancer cells to spread via a contiguous route to the tubogastric mouth and involve its lumen. In those few instances of carcinoma involving the lower third of the esophagus as well as the cardia and fundus of the stomach, the procedure of choice is jejunostomy.

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NINE YEARS' CLINICAL EXPERIENCE WITH STEEL WIRE AS A SUTURE MATERIAL

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OPERATIVE success depends upon mechanical technique, asepsis, and wound healing and despite the advances in laboratory and clinical research, little progress has been made in understanding or improving this latter fundamental operative requisite. While the necessity for anatomical reapposition and a minimum of trauma has been stressed, these requirements in many instances are imperfectly practiced. In the utilization of sutures and ligatures, the advance has been particularly slow. Such important matters as the selection of sutures have been left to the hospital purchaser, and the note on the operation sheet "routine abdominal closure" is an admission of content to follow out-dated and traumatizing methods of ligation and wound suturing. The publication of 126 articles on sutures and ligatures in the last 3 years is a more encouraging indication of the awakening to the responsibility for this important portion of the operation.

Ligating and suturing necessarily are as old as surgery. Not only were nonabsorbable sutures used, but catgut was described by the Arabian Rhazes, who wrote in 900 A.D. of the stitching of wounds with strips of sheep intestines. We know that Galen used catgut in addition to other sutures, but it was 1816 before Physick demonstrated the absorbability of this material. With Lister's discovery of the way to sterilize catgut, in 1869, this suturing material became the popular one. The strands were heavy and the needles traumatic, and even such a technician as Kocher reported an infection incidence of 70 to 80 per cent with this suture material. These infections led to his adoption of the silk suture which Halsted popularized after observation of Kocher's experience with the silk suture technique. This silk suture school has persisted in many places to this time. With the advent of the so called modern surgery, where stress was placed upon speed, catgut had a rebirth, and it has remained the most widely used suture material to this day.

At the Babcock Clinic in Philadelphia, dissatisfaction with the serum collections in clean wounds so often manifested after closure with catgut, stimulated an effort to find a more satisfactory suture material. From 1931 to 1935, such materials as cotton, linen, silk, Japanese and American fishline, silver and copper wires were utilized with varying success. Silk in the clean cases, in which the necessary finer instruments and technique were employed, was

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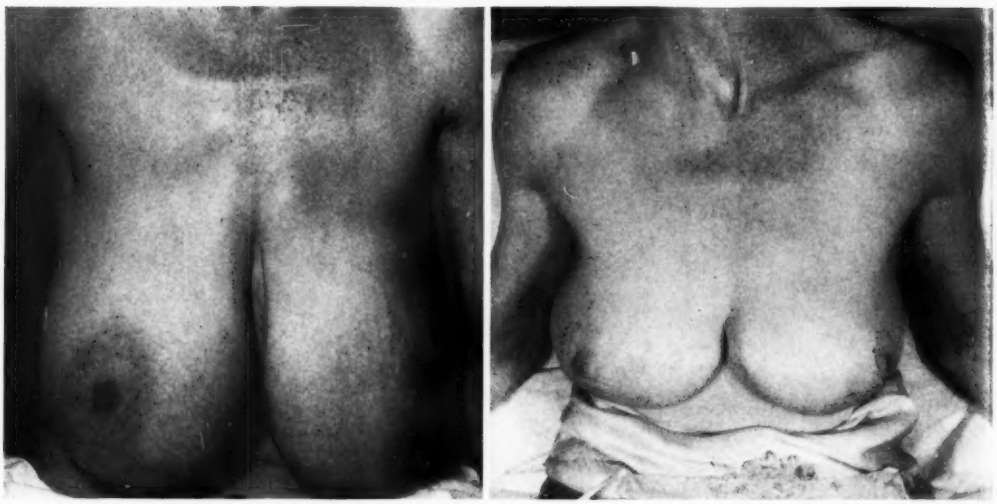

Fig. 1. Plastic for pendulous hypertrophied breasts which reached 4 inches below umbilicus. All sutures were of steel wire. Right, photograph taken 6 months after bilateral operation.

satisfactory. In other instances, in which sepsis was present, the resulting sinuses made it most undesirable. The fishlines, like catgut and some cotton, would absorb fluid, lengthen and swell, with inevitable tensile weakening. Silver wire, so admirably employed by Sims in his closures of vesicovaginal fistulas, had the disadvantage of breaking on the knot and its oxidation subcutaneously left a discoloration.

In 1933 the first alloy steel wire was employed at the Babcock Clinic and a thorough investigation and clinical study were made. In reviewing the work on suture experiments one is confronted with the conflicting reports based on results of nearly identical investigations. These studies were based on animal work. Although animal experimentations are necessary, the results are frequently fallacious, and pro and con interpretations may be made at times from the same results. It is our contention that experiments to demonstrate sensitization and allergic manifestations to sutures should be conducted under circum-

Fig. 2. Hernia repair and plastic removal of large apron of fat after weight reduction. All sutures were of steel wire. Right, primary healing took place despite wound site near area of contamination.

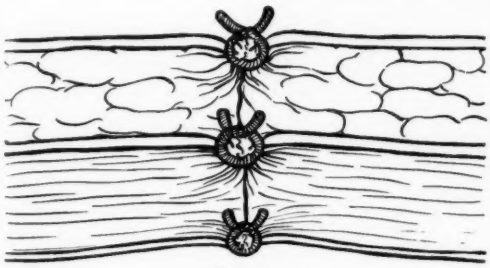

Fig. 3a.

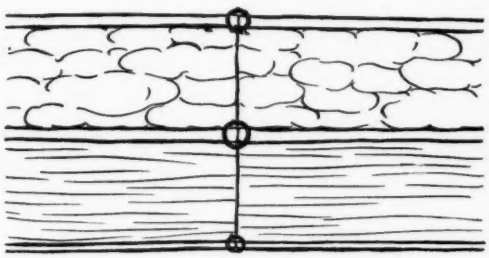

Fig. 3b.

Fig. 3c.

Fig. 3. a, Illustrates the frequent strangulation of tissues in the use of absorbable sutures; strands are heavy and the swelling causes more necrosis. Tissues should be lightly approximated—as shown in b, in which fine steel wire is used. c, Demonstrates tying technique—first knot is tied loosely and a half turn made to hold it. After square knot is complete the ends are cut short and turned under.

stances similar to those in which the sutures are to be used. Preparations and solutions or suspensions of the suture material have the disadvantage of presenting the material to the host in an unnatural fashion. Sutures, themselves, inserted in the human exactly as they will be presented in the wound closures, is the ideal way to test for the body's response to these foreign materials.

The author, under Dr. Babcock's directions, implanted some 750 sutures of different materials in surgically prepared areas in 125 patients to learn the reaction of the patients to these materials. Sutures of plain No. 1 catgut, chromic No. 1 catgut, silkworm gut, alloy steel wire, silver wire dermal, and various types of fishline were inserted through the skin in different areas of the surgically prepared field and gross, bacteriological, and at times pathological observations were made, at 5 day, 7 day, 10 day, and 14 day intervals. The report of this work has been published previously (Babcock, 1935) but in every in-

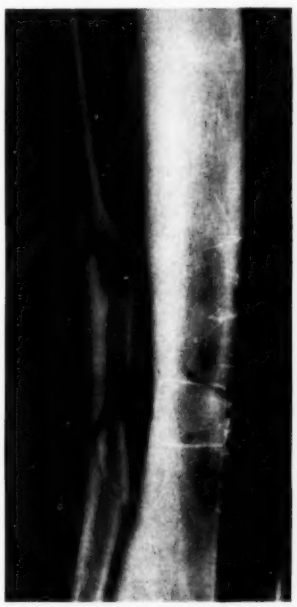

Fig. 4. Compound fracture of tibia and fibula with large skin defect. Previous fracture had occurred at same site and 14 operations had been done for osteomyelitis of this leg. Bone union was effected and a skin graft applied. Wire sutures only were used.

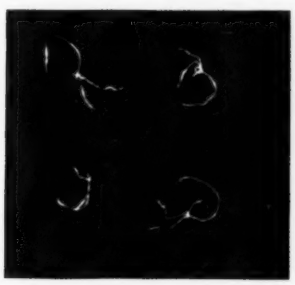

Fig. 5. Steel wire which was removed after 4 months in compound fracture tibia and fibula. Notice how shiny and noncorroded the sutures are. Bone union was complete.

Fig. 6. Photomicrograph of fascia with steel wire, 4 years after insertion in ventral hernia repair. There was no tissue reaction to suture material. ×45.

stance in which catgut was used, a reaction varying from a flare to a distinct pustular response was noted. Silk was variable in its

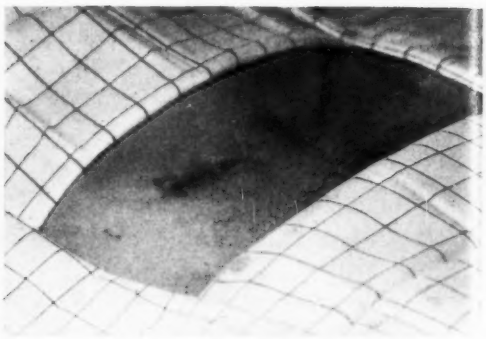

Fig. 7. Wound seventh day after operation for ruptured appendix and closure with steel wire. While there has been drainage the suture areas are clean and nonirritated.

response, but at the end of 10 days in over 50 per cent there was some necrosis surrounding the suture. Wire gave the least reaction and the steel, without the skin discoloration due to the oxidation of the silver wire, was quite imperceptible in 95 per cent of the cases. In the last year a second series of experiments on patients have been performed. Four suture materials, chronic catgut, silkworm gut, silk, and steel wire have been placed near clean surgical wounds. Each strand has been passed

Fig. 8. Roentgenogram of multiple steel wire sutures buried in fascia in hernia repair.

Fig. 9. High amputation for obliterative vascular disease. Closure with steel wire. Primary union.

through the deep fascia, and the sutures have been subjected to a regulated strain at various intervals after operation. Results so similar to the experiments previously reported have been obtained that the previous work is collaborated.

The allergic factor in catgut has been subject to more study. The work of Kraissl, Kisten, and Cimotte was confirmation of the factor of allergy to catgut in wound healing. They reported disruption in 35.7 per cent of the abdominal wounds in guinea pigs previously immunized with catgut and a sensitivity reaction to catgut in 332 humans. Hinton's findings that 9 of 112 patients who had had a previous operation were sensitive to fresh sheep gut (0.8 per cent solution) is further confirmation of the part reaction may play in the various stages of dehiscence. Taylor's report that catgut is a culture medium has been confirmed many times, and Whipple was able to reduce his incidence of wound infections from 7.55 to 2.04 per cent by changing from catgut to silk.

It is obvious that the ideal suture material is one in which there is a minimum of trauma necessary to insert it, a tensile strength sufficient to assure its maintenance and the least possible tissue response to it. In our experience steel wire fulfills these requirements more satisfactorily than any other suture at present available.

For the last 8 years, steel wire has been employed to exclusion by the author as retention and skin sutures with success in all abdominal as well as other wounds. It has been buried in the closure of fascia in inguinal and all ventral or incisional hernias. It has been particularly successful in the presence of sepsis and its efficiency has permitted primary closures in appendicitis with peritonitis, in colostomies after 1st stage Mikulicz operation and in fistulas. It has replaced all other sutures in plastic operations (Figs. 1 and 2).

As in the use of silk, the technique must be varied. Small bites of tissue should be taken (as shown by Preston's experiments) and smaller needles and finer instruments with less trauma are utilized. Tissues must be merely approximated, without pulling the knot tightly, as the steel wire will not give with tissue swelling. A square knot should be tied and the ends cut on the knot (see Fig. 3). The surgical nurse must prevent kinking of the wire during its preparation and the first assistant can save valuable time by following the suture through to prevent a wire snarl. The wire should be of such size as to have only sufficient strength for the purpose for which it is being used. A No. 36 or No. 37 on the Sharpe and Smith gage is effective in the skin, while a No. 33 or No. 34 makes an ideal buried fascia suture. For heavy bone approximation a No. 30 gauge is sufficient (see Figs. 4 and 5). For the bowel, fine No. 36 interrupted steel wire suture is well tolerated and especially effective on the serosal surfaces; will cause so little reaction that the tendency to adhesions and obstruction is minimized. Jones and his co-workers have confirmed the incidence of lowered infection by the use of wire in bowel work. His report of a reduction of infection in abdominal wounds after 116 cases of resection of the colon from 27.5 per cent in those in which catgut was used to 0.85 per cent in those cases in which alloy steel sutures were employed, is so significant that further comment on this work is unnecessary.

In this last year, during an operation for carcinoma of the cecum, an opportunity was presented to study steel wire buried in a ventral hernia closure 4 years previously. The fascial section and wire were excised, and not only were the sutures bright and shining, but the surrounding tissue showed neither gross nor microscopic evidence of tissue or foreign body response (Fig. 6, ×45).

In the 9 years that this suture material has been used, we have never seen tissue reaction to it. In a few instances in which overenthusiastic residents have squeezed the wound edges by ligating the sutures too tightly, a local necrosis has developed, due to constricting avascularity. In an analysis of the last 145 appendix operations in which 75 were of the acute, gangrenous type, all closed with the steel wire, there has been wound edge infection in only one. Figure 7 shows the abdominal wound 7 days after removal of a ruptured gangrenous appendix. While there has been drainage, it has been between the

sutures which are still *in situ* and no reaction has occurred around them, nor has there been wound breakdown.

In 85 inguinal hernioplasties, steel wire has been used to close the layers from the peritoneum, while in all recurrent inguinal and ventral hernias the wire has been buried in the fascia. Experience with wire as the only suture in hernias has led to its adoption for even suturing the base of the sac and transplanting the base under the rectus muscle. An x-ray film shows buried steel wire in the fascia of a large ventral hernia 4 years after operation. Sutures were of No. 34 alloy steel wire, and the wound healed primarily (Fig. 8). There has been but one recurrence and this was in a ventral hernioplasty in an elderly individual with bronchiectasis who had had 2 recurrences before and who "coughed his hernia out" in the first 48 hours. In these hernias we believe that wire plays a most important part and in our hands is much more satisfactory than such foreign materials as silk, kangaroo tendon, or the routine fascial transplants. The fascial sutures require such traumatic needles and large openings that it is surprising not to observe some with recurrence due to needle apertures alone.

In major amputations for vascular disease when only steel wire has been used in closure, we have had 92.3 per cent primary unions in the last 3 years, 26 cases. Figure 9 demonstrates how primary healing is obtained even in high amputations with the steel wire. The stump is in an easily contaminated area, but healed satisfactorily. Previous experience with other suture materials was not satisfactory.

The wound after ligation of the saphenous vein at the fossa ovale has been approximated with the wire and the infections so prevalent in this area when we used silk have been reduced to 8 in the last 150 patients.

With many others we have felt that wound disruption or avulsion is most often due to inadequate postoperative support, rather than the type of operation, a predeliction or autonomous suture destruction. At one time we saw three avulsions on a surgical service in a month following the routine adoption of Montgomery strings instead of adhesive strap support. The incidence of diathesis is greatest at the time of retention suture removal. Prior to burying the wire fascia sutures it had been our practice to retain the retention sutures *in situ* for a long time and even to permit patients to leave the hospital with the sutures in place. This was easily handled as one felt safe in doing this with the steel wire as no suture abscesses will be formed. In more than 500 major abdominal operations there has not been a wound disruption. In one instance in which a double barrelled colostomy after a 3 stage Mikulicz operation for carcinoma of the hepatic flexure was closed primarily with the steel wire only, the patient returned 2 years later complaining that she felt a wire suture. Examination showed one of the wires had become unknotted and its tip was presenting at the skin edge. Its removal was simple and this patient has had no other complaints in 5 years of observation.

SUMMARY

Nine years' clinical observation has confirmed experimental work showing less tissue reaction to steel wire sutures. It is effective in abdominal closures in which it may be used as a buried suture and, in infected or contaminated areas, it is particularly indicated. A finer technique and approximation without strangulation is necessary in its use. It has been adopted to exclusion in all hernias and markedly reduced the morbidity and the disability time. Patients so sutured may be returned to industrial work in 4 weeks rather than the routine 8.

Its wide use in intestinal anastomoses, as the serosal sutures and in the plastic surgery field is stressed.

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A STUDY OF THE EFFECT OF MORPHINE, ATROPINE, AND SCOPOLAMINE ON THE BRONCHI

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THIS study is concerned with the effect upon the tracheobronchial tree of the commonly prescribed drugs or combination of drugs, for premedication to anesthesia, and with morphine, the drug most commonly used for postoperative relief of pain. The drugs studied were: morphine sulfate, ¼ grain; atropine sulfate, 1/50 grain; scopolamine hydrobromide, 1/100 grain; morphine sulfate, ¼ grain; and atropine sulfate, 1/50 grain; morphine sulfate, ¼ grain and scopolamine hydrobromide, 1/100 grain.

There has been considerable speculation and controversy over the mode of action of these drugs on the bronchi and in what manner they affect the bronchial secretions which are brought to the oropharynx. Certainly, opinions on the subject vary among clinicians. This difference of opinion may be due to the fact that conclusions are drawn from infrequent clinical observations rather than laboratory or clinical experimentations.

Waters and others, in studying these drugs demonstrated that in so far as their effect upon respiration, circulation, blood pressure, tidal exchange, minute volume exchange, and nausea and vomiting was concerned, the combination of morphine and scopolamine was the most satisfactory. They also showed that the most marked depression in respiration and circulation occurred 1½ to 2 hours after administration of these drugs.

On the basis of our studies and clinical observations both the surgical and anesthesia departments of the Wisconsin General Hospital have concluded that the combination of morphine and scopolamine in individualized doses in the ratio of 25:1 has the least depressant effect upon the raising of bronchial secretions and the suppression of cough reflex.

In order to obtain some definite data on this subject a clinical experiment was carried out on a young white female who presented a bronchopleurocutaneous fistula. Her case history follows:

White female, aged 18 years, was admitted to the Wisconsin General Hospital on May 29, 1940, with the chief complaint of a "lung abscess." Following a fourth operation in 1938 for intestinal obstruction, she developed a left lower lobe lung abscess. She was treated in two other clinics before her admission. The treatment had been conservative, consisting of inadequate postural drainage, bronchoscopic aspirations, bed rest, diet, and "tonics." Her progress was unsatisfactory, and she was referred to this hospital. Her complaints on admission were as before; namely, intermittent fever, cough with the raising of sputum, hemoptysis, weakness, and weight loss.

On admission her temperature was 101.8 degrees; and the patient appeared toxic, undernourished, and chronically ill. Physical findings were consistent with a left lower lobe lung abscess. X-ray studies revealed bronchiectasis, atelectasis, and encapsulated fluid in the left lower lobe. X-ray also revealed a chronic pansinusitis.

In view of the inadequate conservative treatment previously, the patient was again given a trial on postural drainage, which resulted in no improvement. Therefore, on June 27, 1940, cautery drainage of the lung abscess was instituted. Multiple small abscess cavities were encountered and aspirated, and a pack was inserted. On the seventh postoperative day the pack was removed, and a large abscess cavity with many bronchopleurocutaneous fistulas was noted. Following this her condition improved rapidly. She gained 50 pounds in weight in 6 months. No cough, sputum, fever, or abnormal blood counts persisted at the time of discharge. A large bronchopleurocutaneous fistula was still present.

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METHOD

The experimentation was not begun until the patient's sputum and cough were gone and she was gaining weight. After the experiment was completed, lipiodol was instilled, both through the fistula used for the experiment and from above through the trachea, and the diagnosis of bronchiectasis of the left lower lobe was confirmed. The lipiodol which was instilled through the bronchopleurocutaneous fistula was seen to enter a relatively large bronchus in the left lower lobe.

All of the data for this experiment were obtained by the same operator so that the technique followed was uniform. An easily accessible, fairly large bronchial opening (a bronchopleurocutaneous fistula) was selected and used throughout.

Powdered carmine dye was deposited by means of a small eye curette into this same bronchial opening. Carmine dye was used because of its insolubility and lack of absorption in body secretion and because it is nonirritating. Its bright color made it easily detectable in small amounts. The dye was deposited just within the bronchial opening during ordinary inspiration with the patient

TABLE I.—EFFECT OF DRUGS ON APPEARANCE TIME OF CARMINE DYE

Drugs and dosages	Number of trials	Average time interval between giving of drug and dye–hours	Average appearance time—minutes	Percentage change from Control time of 8.66 minutes*
Morphine gr. ⅛	5	2	8.6	±
Morphine gr. ¼	3	2	11.0 8.3 } 9.6	+27.9 −3.4 } +11.6
Morphine gr. ¼	3	1½		
Atropine gr. 1/100	5	1	11.7	+36.0
Atropine gr. 1/50	6	1½	11.8	+37.2
Scopolamine gr. 1/200	1	1¼	7.0	−18.6
Scopolamine gr. 1/100	4	1¼	8.4	−2.3
Morphine gr. ¼ Scopolamine gr. 1/100	6	1¾	14.0	+62.7
Morphine gr. ¼ Atropine gr. 1/50	5	1½	17.8	+107.0

*The positive percentage indicates the increased time while negative percentage indicates decreased appearance time.

on her right side. It was deposited during inspiration because the expiratory blow from the bronchial opening was sufficient to blow the fine powder from the curette, thus making it impossible to get any of the dye into the bronchus. It was appreciated that the height to which the dye was inspired was variable, but it was sufficiently uniform so that the ranges of the control "appearance times" were uniform.

The dye was deposited 1½ to 2 hours after the hypodermic injection of the drug being studied. The reason for the selection of this time interval is that Waters and others have shown that the maximum effect of these drugs is secured between 1½ to 2 hours after their administration hypodermically.

The patient remained on her right side after the dye had been deposited. The time of deposition was noted and recorded. A third person sat at the bedside and recorded the first appearance of the dye in the sputum. The patient was intelligent and co-operative throughout the period of the experimentation. She did not cough until she got the stimulus to cough; i.e. until the cough reflex was stimulated by the foreign particles. The dye almost invariably appeared with the first cough. After two to three consecutive coughs the stimulus was gone. No more dye appeared even though she coughed later in the day. The time between the deposition of the dye and its first appearance in the sputum will henceforth be called the "appearance time."

Only one trial was performed a day in order to avoid cumulative effect of the drug, and often one day or more was allowed between trials to avoid addiction to the morphine. The patient did not know what the medication was nor what its effect should be.

Before the controls to this experiment were performed, many daily carmine dye instillations without medication were done until it was determined that the results were uniform. At this point it was decided that the effects of the acute infection and of the surgery upon the bronchial tree were past, and that the results were due to normal action of the bronchi themselves. A subsequent left lobectomy and pathological study showed bronchi with normal cilia. During the course of experimentation the sputum was at a minimum and there was no drainage from the bronchial opening.

RESULTS

It was found that the position assumed by the patient made no difference in the appearance time of the carmine dye. Trials with the patient on her right side, on her left side, on her back, and in the sitting position gave comparable results. Because of the ease with which this experimentation could be done with the patient on her right side, this position was chosen as the one of choice for the trials.

Fifteen control instillations, without medication, were performed. The average appearance time (that is the time elapsing between the instillations of the carmine dye and the dye appearing in the sputum) was 8.66 minutes. Controls were performed also during and after the trials with medication, and it was found that the control times remained uniform.

The drugs were then tested in the dosages as given, and the percentage change from the control time of 8.66 minutes was calculated, as shown in Table I.

The question, of course, then arose as to how long these drugs exerted their effect. Attempts at repeated dye injections were then tried. It was found that the experiment could satisfactorily be carried out for only a period of 3 hours. The results of these trials appear in Table II.

EVALUATION

The function of raising secretions or small foreign particles from the bronchi probably depends locally on three separate actions, namely: (1) the character of the bronchial secretions, (2) the action of the bronchial cilia, and (3) the cough reflex. Any variation from normal in any one of the actions may cause a deviation from normal in the appearance time.

It was realized at the outset that an experiment of this sort has many sources of error. These were minimized and eliminated wherever possible. We are not, therefore, interested in the actual appearance times, but rather in the "trend of change" as indicated by the percentage change over the normal control times, and the comparative amount of change caused by one type of medication as compared to the other. We feel sure that these results do indicate the trend of change and the comparative amount of change caused by these drugs on bronchial action.

Atropine and scopolamine themselves have little, if any, depressive action, but they do change, both objectively and subjectively, the character and amount of the secretions from the mucous glands. Whether they have any depressive or stimulating action on the cilia of the bronchi is not known. We do know that morphine causes a generalized depression of cellular metabolism and irritability. That it has a depressive action on certain respiratory functions has already been indicated (1, 2). It causes depression in the cough reflex. If morphine affects these ciliated cells as it affects most other cells of the body, we can rightly surmise that the ciliary action is also depressed.

With morphine alone the appearance time was increased 11.6 per cent over that of the control. The effect here was probably due to the generalized depressive effect, especially of the cough reflex and of ciliary action.

With atropine alone the appearance time was greatly increased, 36 per cent over the control, more so even than with the morphine alone. The cause of this perhaps lies mainly in the change in the amount and character of the bronchial secretions.

Scopolamine alone apparently had little effect. We know however that scopolamine does at least change the amount and character of the secretions, but in this experiment the change apparently was not sufficient to alter the appearance time noticeably.

When the combination of morphine and atropine was used, the change was more marked than with either drug alone, 107 per cent as compared with 11.6 per cent and 36 per cent. The appearance time was greatly prolonged. The drugs apparently here have a synergistic action, with all three of the factors, namely, bronchial cilia, cough reflex, and bronchial secretions, being altered to cause this increase in appearance time.

When morphine and scopolamine were given together, the appearance time was again greatly increased although the change was not as marked as appeared with the morphine and atropine together, 62.7 per cent as compared with 107 per cent. It was prolonged greatly as compared with either drug alone, 62.7 per cent as compared to 11.6 per cent and −2.3 per cent, and apparently their actions were again synergistic.

TABLE II.—EFFECTS OF DRUGS ON APPEARANCE TIMES AFTER 3 HOURS

Drug and dosages	Number of trials	Average time interval between giving of drug and of dye—hours	Average appearance time—minutes	Percentage of change from control time of 8.66 minutes
Morphine gr. ¼ Atropine gr. 1/50	5	3	14.5	+91.8
Morphine gr. ¼ Scopolamine gr. 1/100	4	3	11.0	+27.8

The results of the repeated dye injections show that the effects of the drugs are prolonged, in this case well over 3 hours from the time of giving the drugs—morphine-atropine combination 91.8 per cent over the control, and morphine-scopolamine combination 27.8 per cent over the control.

When comparing the relative effects of the morphine and atropine, and morphine and scopolamine, they bear out what we have always felt clinically at this hospital, but have never shown experimentally before: namely, that the morphine and scopolamine given in individualized doses (ratio here is 25 to 1) is a better preanesthetic combination than the former. The percentage change of morphine and atropine here over the control was almost twice that of the morphine and scopolamine.

SUMMARY

1. Morphine sulfate, atropine sulfate, and scopolamine hydrobromide were studied both alone and in combination, to determine their effect upon the bronchial tree, in a patient with a bronchopleurocutaneous fistula. The "appearance time" of the carmine dye was used as the method of testing the effect of drug action.

2. In 15 control experiments, the average appearance time of the dye was 8.66 minutes. The control time was checked during the course of the experiment and was found to be uniform.

3. Morphine sulfate caused an increase in the appearance time of 1.0 minute, or a percentage change of 11.6 per cent over the control.

4. Atropine sulfate, 1/100 grain, caused an increase in the appearance time of 3.1 minutes, or 36 per cent over the control. Atropine sulfate, 1/50 grain, caused an increase in the appearance

time of 3.2 minutes, or 37.2 per cent, change over the control.

5. Scopolamine hydrobromide caused a decrease in the appearance time of 0.2 minutes, or a −2.3 per cent, change over the control.

6. Morphine-atropine combination increased the appearance time 9.2 minutes, or a 107 per cent, change over the control.

7. Morphine-scopolamine combination increased the appearance time 5.4 minutes, or a 62.7 per cent, change over the control.

8. Three hours after the morphine-atropine had been given, the appearance time was increased 5.9 minutes, or a 91.8 per cent, change over the control.

9. Three hours after the morphine-scopolamine had been given, the appearance time was increased 2.4 minutes, or a 27.8 per cent, change over the control.

10. The sources of error in this type of experiment were appreciated. As a result the trend of change and the comparative amount of change of one medication as compared to another are the findings of importance in this study, rather than the actual appearance times.

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A SIMPLE OPERATION FOR STABILIZATION OF THE KNEE JOINT

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An operation for stabilization of loose knee joints following injury to the crucial ligaments is described herein. The operation is simple to perform; it does not necessitate opening of the knee joint; it eliminates the need of long postoperative immobilization; and it makes possible, and desirable, early walking with the aid of a knee cage.

Looseness of the knee joint as a result of injury to the crucial ligaments is a serious disability. Milch pointed out that injury to the crucial ligaments usually involves other supporting structures of the knee, particularly the internal lateral ligament when the anterior crucial has been traumatized. He believed that primary surgical treatment should be directed toward the repair of the internal lateral ligament rather than the cruciate. Bennett stated that a knee may be fairly stable in spite of severance of the anterior crucial ligament, provided that the internal lateral ligament is normal. According to Cubbins and his associates, early operation following complete dislocation of the knee is not indicated. They advised immobilization of the knee for 120 days, arguing that some knees so treated will recover.

The operation which Hey Groves (5, 6) described for the repair of torn crucial ligaments with fascia lata established the principles upon which most of the subsequent repairs have been based. A modification of the Hey Groves operation to include strengthening of the internal lateral ligament was later reported by Alwyn Smith. Fascial transplants, however, do not restore a knee to normal function after long continued disability due to injury of the collateral ligaments of the knee even though stabilization may be effective (9).

Less difficult procedures than those advocated by Hey Groves and Alwyn Smith have since been devised and have given satisfactory results. Bennett plicates the capsule and uses two parallel strips of fascia for further reinforcement (Fig. 2, A). Cotton and Morrison draw a strip of fascia through holes drilled in the tibia and femur, crisscrossing the strip as it is pulled through the hole (Fig. 2, B). Ryerson, has modified this procedure somewhat; he drills the holes in the tibia about 7/8 inch apart, making the anterior hole at a lower level, and ties a square knot in the fascial strip near the femur before he draws its long end through the tibia (Fig. 2, C). D. M. and B. M. Bosworth implant a fascial strip in a tunnel in the posterior part of the tibia, draw it through another tunnel in the femoral epicondyle, then pass it through a tunnel in the anterior part of the tibia, and finally suture the fascial strip at the femoral epicondyle (Figs. 2, D and 2, E). The Bosworths stated that when the external collateral ligament is repaired, the attachment may be made to the tibia and the head of the fibula.

The operation now reported is based on Testut's observation that movement of the knee joint is centered in the posterior portion of the femoral condyles. By superimposing roentgenograms

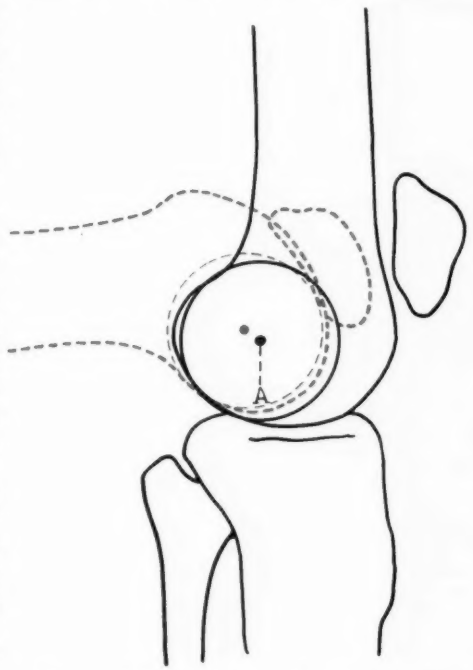

Fig. 1. Schematic drawing of roentgenograms taken with the knee in complete extension and 90 degrees' flexion. *A* indicates nearly fixed point.

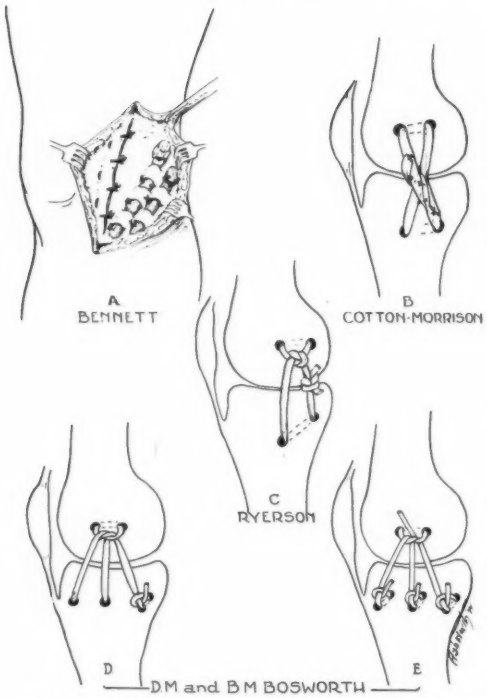

Fig. 2. Stabilization operations previously described in which the reinforcement is placed on the medial or lateral side of the knee.[1]

taken with the knee in extension and at different angles of flexion, a nearly stationary point is localized in the center of the ring formed by the extension of the arc made by the posterior and inferior portions of the femoral condyles (Fig. 1). Theoretically, this point does not change its distance from any fixed point in the tibia during flexion and extension of the knee joint. A strip of fascia applied so that it crosses the fixed point, as is done in the present operation, will therefore remain at the same degree of tension with the knee in extension and in any degree of flexion. Practically, this arrangement of fascial strips has been successful since it has given good functional results under adverse conditions.

It has now been almost 10 years since I performed the first stabilization operation by the method now described. Up to the present time I have performed this operation on 10 patients.

[1]These drawings are reproduced by permission of the various authors and the publishers of the periodicals in which they originally appeared: Bennett, Arch. Surg.; Cotton and Morrison, New England J. Med.; Ryerson, Surg. Clin. N. America (by W. B. Saunders Company); and Bosworth, J. Bone & Joint Surg.

Two patients who were re-examined in 1939, 8 years after the operation, reported that they had had no disability during this period. One was then employed as a truck driver, although the industrial accident commission had paid him 60 per cent lost function of a leg 6 months after the operation. The other patient was working as a hook tender in a logging camp, and had been employed continuously at this arduous work since approximately a year following his operation. This patient had been awarded 45 per cent lost function of a leg 3 months following the operation.

OPERATIVE TECHNIQUE

A strip of fascia, approximately 12 inches long and 1 inch wide, is removed from the fascia lata of the contralateral extremity. A stripper is not used because it is difficult to obtain fascia of the proper width and length by this means. The fascia is cut into four strips, each of which measures approximately ½ inch in width and 6 inches in length. The strips are tied into Gallie needles, and placed in a piece of gauze soaked in saline.

After the fascia has been prepared, an incision 6 inches long is made in the midline on the lateral side of the affected knee. A similar incision is also made on the medial side of the same knee. The skin and the superficial fascia are then dissected free from the deep fascia for a distance of 2 inches on either side of both incisions.

Lateral side (Fig. 3). The first fascial strip is placed in the insertion of the biceps muscle at the head of the fibula, and its lower end is secured in place by suturing it through itself. It is then carried obliquely forward to a position near the superior pole of the patella. Here the free end is passed deep into the tendinous expansion of the suprapatellar tendon, turned back on itself, held tightly in place, and secured with a number of interrupted catgut sutures. The fascial strip does not penetrate the knee joint.

The second fascial strip is attached to the deep fascia on the anterolateral surface of the tibia. This strip is carried obliquely backward, crossing the first, and its free end is fastened securely to the fascia and some of the fibers of the biceps muscle. The two strips should cross on a level with the fixed point in the femoral condyle.

Medial side (Fig. 4). The third fascial strip is started as far back as the posteromedial border of the tibia, at about the same relative level as the head of the fibula and is buried deep in the fascia which in this region covers the tendons of the internal hamstring muscles. Some of the fibers of these tendons may be included in the suture. The fascial strip is then brought obliquely forward and

Fig. 3. Lateral view of the knee showing the order of placing the fascial strips, the method of their fixation, and the tension of the tissues after the fixation is completed.

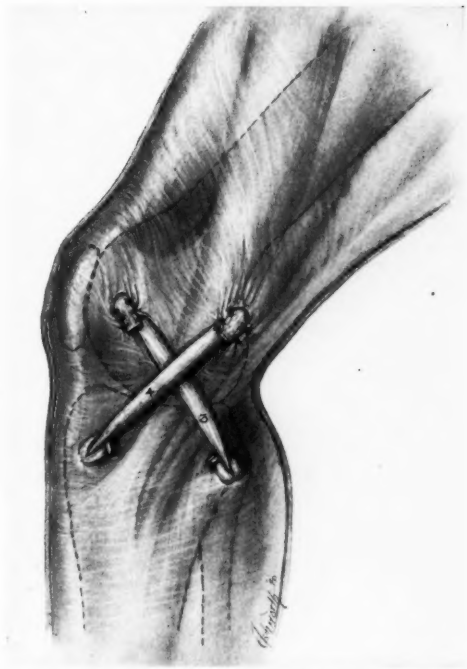

Fig. 4. Medial view of the knee showing the method of the placing of the 3rd and 4th crossed fascial strips in this region.

upward, and its free end is inserted just medial to the superior pole of the patella.

The fourth fascial strip is started at the same level, on the anteromedial border of the tibia. It is carried obliquely backward and upward, crossing the third strip, and is sutured to the fascia overlying the internal hamstrings. The suture may include some of the fibers of these muscles. These two fascial strips, like the first two, should cross on a level with the fixed point in the femoral condyle. When all the strips have been sutured into place, the first runs parallel to the third, and the second to the fourth.

No sutures are used except those of interrupted catgut which secure the fascial strips as described. The skin of each incision is usually closed with silk, and a compression dressing of sterilized cecil cotton[1] is applied.

When the skin stitches are removed, a nonpadded walking cast, extending from the groin to, and including, the toes of the affected extremity, is applied for 2 weeks (the postoperative care of the first 2 patients did not include the nonpadded cast). During the 2 weeks' period the patient is urged to bear some weight. At the end of this time, a long knee cage with 12 inch leather thigh and leg cuffs is supplied. The cage allows 10 degrees' flexion at the start. Flexion thereafter is gradually increased over a 2 or 3 months' period of time.

Abnormal mobility is present in the knee for some time after the operation. And often the hypermobility increases during the 4 to 5 weeks' period immediately following the operation. After this, however, the knee will begin to tighten. The patient is permitted to walk as he sees fit, and no limit is placed on his activities so long as he wears the brace with which he is supplied. Some of the patients have returned to work before this support was removed. The brace should be worn until the quadriceps muscles have developed and the hypermobility of the knee joint has decreased. Sometimes it is necessary to wear the knee cage for 5 or 6 months, or even longer.

[1]Cecil cotton is a nonabsorbent, bleached batting which comes in 8 ounce weight containing 50 per cent staple cotton and 50 per cent cotton linters; and in 16 ounce weight containing 75 per cent staple cotton and 25 per cent mill run linters. A good grade of nonabsorbent, bleached cotton batting would be just as satisfactory.

CASE REPORTS

CASE 1. E. D., male, aged 37 years, was admitted to St. Vincent's hospital on December 6, 1931, because of weakness in his right knee. He stated that he could feel the knee joint "pop in and out" during flexion, and that the knee dislocated backward and laterally. This knee had been injured on February 6, 1931, and in May of that year the internal semilunar cartilage had been removed.

On examination the patient was found to have a torn posterior crucial ligament. The knee joint was extremely lax.

The stabilization operation now reported was performed on December 8, 1931. Three weeks later the patient was discharged from the hospital. At that time he was fitted with a long knee cage which allowed approximately 10 degrees' flexion at the knee. Six months after his discharge his claim with the industrial accident commission was closed with a permanent partial disability award of 60 per cent.

This man was re-examined in 1939, approximately 8 years after his operation. He was then employed as a truck driver. He had, however, first returned to his former work in the woods and had been able to continue it. During his work in the woods he had noticed that when he jumped from one log to another he usually alighted on the extremity which had not been operated upon. Nevertheless, a few years later he had been able to take part in a log rolling contest.

CASE 2. L. G., male, aged 30 years, was admitted to St. Vincent's hospital on February 9, 1932, complaining of weakness and abnormal motion of the right knee. He had sustained a fracture of the right tibia involving the knee joint on January 28, 1931.

On examination it was found that the right leg could easily be moved on the thigh both anteriorly and posteriorly. There was also some increase of mobility medially and laterally.

The stabilization operation was carried out on February 11, 1932, and on March 10, 1932, the patient left the hospital. The cast which had been placed on the extremity at the time of the operation was removed before the patient was discharged. After his discharge he wore no support. On June 10, 1932, his claim with the industrial accident commission was closed with a permanent partial disability award equal to 45 per cent lost function of a leg.

This man was also re-examined approximately 8 years after his operation. At that time he stated that he had not been disabled by the knee, and that he never thinks about it any more. He had returned to his job as a hook tender in a logging camp about a year after the operation, and had been employed continuously since then. His work was arduous and dangerous, and necessitated jumping and moving about quickly on uneven ground.

CASE 3. J. H., male, aged 44 years, had been injured on August 13, 1937, when a large log rolled against the outer side of his lower right leg. A smaller log had struck the thigh on the inner side, causing a dislocation of the right knee. The dislocation had been reduced immediately, and a cast had been applied. Following this the patient had continued to wear a support until November 23, 1937.

Examination on January 3, 1938, revealed instability of the right knee, some genu recurvatum, and weakness of the external lateral ligament. It was possible to displace the knee anteriorly and posteriorly. The peroneal nerve was paralyzed.

On April 1, 1938, the stabilization operation was performed. At the same time the peroneal nerve was exposed at the point where it crosses the fibula, and considerable scar tissue was removed from this region. After the stitches were removed a nonpadded cast was applied. Two weeks later the patient was supplied with a brace.

In August, 1940, the patient returned to work. He was re-examined on September 11, 1940. At that time his knee was completely stable, and the function of the peroneal nerve had returned. The patient said that he had been working in a logging camp.

CASE 4. J. C. V., male, aged 36 years, had twisted his right knee on August 31, 1937, when he had fallen between two logs. He had been able to continue his work by not allowing his knee to extend completely. On March 12, 1938, the internal semilunar cartilage had been removed.

Examination of the right knee on August 25, 1938, revealed that the anterior crucial ligament was torn and that the internal lateral ligament was also injured. In addition, there was some stretching of the posterior crucial ligament. The knee could not be displaced backward to any great extent, yet the patient had a genu recurvatum.

On September 29, 1938, the operation for stabilization was performed. The nonpadded cast was applied after the stitches were removed. And a brace was supplied 2 weeks later.

When this man was examined again on May 21, 1941, it was observed that the knee was stable as far as forward and backward displacement were concerned, but that there was still some back knee. This caused slight disability.

I now believe that after operation on patients who present back knee, the knee should be placed in about 15 degrees of flexion for at least 6 weeks before movement is begun.

CASE 5. C. K., male, aged 46 years, was examined on August 21, 1939. It was found that the right leg could be displaced forward on the femur when the knee was in slight flexion. A diagnosis of torn anterior crucial ligament was made. This man stated that he had dislocated his knee on March 15, 1931, when he had jumped off a board. On August 28, 1939, the stabilization operation was performed. The nonpadded cast was applied after the stitches had been removed, and 2 weeks later a brace was supplied. A little over a year following the operation the patient returned to his work felling timber. In a letter written on June 1, 1941 he stated that "the operation was certainly a wonderful success."

CASE 6. F. K., male, aged 24 years, was seen on October 12, 1938, because of an injury to his left knee which he had sustained while playing football. A diagnosis of torn internal semilunar cartilage and injury to the crucial ligaments of the left knee was made.

On May 3, 1939, the left internal semilunar cartilage was removed. And on October 10, 1939, the stabilization operation was performed. Following this procedure the extremity was placed in a nonpadded cast. Later the patient was given a long knee cage.

This young man was re-examined on November 27, 1940. At that time anterior displacement of the tibia on the femur was still present.

The displacement, I believe, is probably due to relaxation of one of the fascial strips which occurred shortly after the operation. I have not been able to obtain permission to operate on this boy again. Meekison, however, reopened the incision on the medial side of the knee of one of his patients because of the same complication. One of the fascial bands, he found, had failed to hold and had to be resutured into position. The other was in place and had greatly hypertrophied.

Sufficient time has not yet elapsed to determine the outcome of the last 3 operations. One patient could not be traced.

SUMMARY AND CONCLUSIONS

The operation which has been described herein was first attempted because the patient had refused to have his knee opened, yet, because of the severity of his condition, required some stabilization procedure. From a cursory examination of the present technique, it would seem that fascial strips which are not drawn through bone cannot stabilize the knee joint. Practical application of this procedure over a long period of time has, nevertheless, except for 1 instance, been successful. This, it would seem, proves that it is not absolutely necessary to anchor fascial strips in bone in order to secure satisfactory stabilization. Moreover, Meekison, who had occasion to reopen the knee of one of his patients, observed that the fascial strip which had remained in place had greatly hypertrophied. This would indicate that fascial transplants applied in the manner just described have a normal physiological action.

While this stabilization operation has already been successfully carried out following severe injuries to the crucial and collateral ligaments, it is particularly applicable following minor injuries to these ligaments, that is, injuries which make wide exposure of the knee joint inexpedient.

Finally, as has already been stated, the stabilization operation now described is simple to perform; prolonged hospitalization is unnecessary; and the patient within a relatively short time is able to resume his former activities.

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FRACTURE OF THE PATELLA TREATED BY REMOVAL OF THE LOOSE FRAGMENTS AND PLASTIC REPAIR OF THE TENDON

A Study of 554 Cases

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SINCE the turn of the century, until recently, there has been little offered in the way of improvement of existing methods of treating fractures of the patella. By far the most enlightening article I have found on this subject in the last 40 years, was published by Heineck in SURGERY, GYNECOLOGY AND OBSTETRICS, in August, 1909. It consisted of a review of 1100 fractures of the patella collected from Cook County Hospital in Chicago and the American, English, French, and German literature of the preceding 10 years. His objectives of treatment are as pertinent today as they were thirty years ago. They are: "(1) The fracture must be reduced. (2) The bony fragments must be maintained in intimate apposition until organic union has been effected. (3) The continuity of the divided soft tissue must be re-established. (4) The functional integrity of the knee joint must be restored." There were at that time, and are now, few procedures that would always meet these obvious but extremely important objectives.

There are three schools of thought in regard to treatment of fractures of the patella with separation of the fragments, each having virtues and limitations which should be given definite consideration in the estimation of its appropriateness in the management of an individual case. These three schools might be classified as: (1) the restorative treatment; (2) the excision treatment; and (3), the removal of loose fragments with plastic repair of the patellar tendon treatment.

1. *The restorative treatment of fractures of the patella.* There are many surgeons who are still of the opinion that the best results can be obtained by reassembling the fragments by means of wiring through, around, or over them (Hawley, Campbell, Henry), or by suturing through and around with heavy chromic catgut, kangaroo tendon (Scudder), fascia, or silk, in an effort to restore complete anatomical apposition and healing. Those who use fascia indulge themselves in substantial fancy-work in the form of quilting the spreadout terminal portions of the fascia into the tendon substance (Allen, 19) to reinforce lacerated patellar tendon. Others ingeniously use pins (Day), and fixed wire traction devices in casts (Anderson). Bone grafts (Albee), pegs, and screws (Henderson, 14) have been advocated and employed. All of these methods adroitly used accomplish the desired reapposition. However, their high aims too often fall short of giving an ultimate restoration of contour, particularly on the gliding surface of the patella, and lend themselves to complicating sequelae in the form of nonunions, arthritic joint changes, and mechanical obstructions to function.

2. *Excision treatment.* There is a growing popularity on behalf of complete excision of the fractured patella, with remarkably satisfactory results. Heineck found several reports of excision of the fractured patella, with good results, in the literature prior to 1909. Brooke maintains that the extension power is even greater after the patella has been removed; that the function of this sesamoid is nil; and that as a structure it is a vanishing rudiment of evolutionary progress. Herzmark (13) and Heineck, on the other hand, consider the patella as a necessary protection to the knee joint, adding to the power of extension by carrying the quadriceps away from the joint and decreasing the friction between the quadriceps and the condyles of the femur. We (Thomson and Ferciot) agree in part with both these views and believe that although the patella can apparently be removed without much loss of function, one must give due consideration to the fact that the knee joint is the largest, most exposed, and most vulnerable joint in the body; that it is of estimable importance to locomotion, posture, and comfort; and that the patella forms an important protection or buffer to the widely exposed large condyles of the femur, particularly in flexed positions. Therefore, since flexion of the knee is the position in which most fractures of the patella occur, the complete removal of this buttressing sesamoid opens the exposed condyles to the constant possibility of minor and severe direct

bruising injury which could lead to interarticular changes and ultimate future disability. Further, the patella has a cosmetic value which must not be overlooked. Its removal obliterates the normal contour of the knee and creates an asymmetry between the injured and uninjured leg. There is generally, also, fear or apprehension expressed by the patient with respect to possible impairment of stability when removal is suggested. This is particularly true on the part of those engaged in occupations which require them to assume kneeling positions frequently, such as housewives, mechanics, plumbers, the clergy, and so forth. From the standpoint of a compensation or insurance case the removal of a whole bone, sesamoid or long bone, and the resultant defect, constitutes in itself substantial damage and potential disability.

3. Plastic tendon repair and removal of loose fragments. The limitations and disadvantages of the two preceding methods of dealing with the problem of fractures of the patella, from a physiological, anatomical and economic standpoint, have led to the growing popularity of a third school of thought which advocates the removal of all but a single attached fragment. This fragment may form either the distal or the proximal pole of the patella and the opposing patellar tendon is sutured to and through this remaining fragment.

To evaluate the appropriateness of this principle which I recommended years ago, many of the leading fracture surgeons were canvassed by questionnaire, with the result that 113 surgeons responded as having used this method on from 1 to 39 cases. A total of 554 cases have been studied. Of this number 479 have been analyzed with respect to age, sex, type of fracture, number of days between operation and beginning of weight-bearing, period of limited function, length of time between operation and return to work, and resulting ultimate partial permanent disability. There were 75 cases with incomplete statistical data but sufficient information was available from the many comments to prove valuable in making deductions. The 479 cases were divided into two groups. The first 424 cases comprised fractures operated upon within 2 weeks after injury. The second group, consisting of 55 cases, included those operated upon after the 2 week period.

In this series of cases the average age was 40 years. When one considers the ages by decades it is quite evident that this fracture seldom occurs in the very young and very old, and is distinctly a fracture of middle life. Males outnumbered females almost two to one.

Simple comminuted fractures were by far the commoner type in which this procedure was used, although it was used in a large group of simple fractures that were not comminuted. It is interesting to note that this method proved quite adaptable in 56 compound fractures.

Three hundred and fifty-five fractures were operated upon within 2 weeks. In 69 additional cases the exact day was not designated, but other circumstances reported seemed to indicate that they were operated upon early, so therefore they are considered in this group. The average number of days between accident and operation in this group was 3.6 days. However, there were 104, or 29 per cent, operated upon within the first 24 hours and 198, or 55 per cent, within 3 days, while 287, or 80 per cent, were operated upon within the first week and only 68, or 20 per cent, during the second week. Many of the fractures operated upon within a few hours were compound injuries in which débridement and clean up offered a chance of primary closure and healing. It was interesting to note that the more experience a surgeon had had with this technique the earlier he operated.

Of the 55 patients operated upon more than 2 weeks after injury, in 21 repair was done within 2 and 4 weeks, and 16 more were operated upon within 3 months. In this group are the fractures that were referred late to the surgeon, conservative treatment having failed to bring or hold the fragments together. There were 15 compound fractures which, due to tissue injury, infection, and other complicating circumstances, were unsuitable for early closure. Also there were 15 cases of nonunion or separation of fragments, following previous operations to approximate the fragments with wire and other suture material around and through the fragments. The necessity of a secondary operation probably contributed to a portion of the ultimate disability in 8 of these cases; 2, 5 per cent; 2, 10 per cent; 1, 15 per cent; 2, 20 per cent; 1, 30 per cent. Several of the patients in this group had complications of such importance that repair of the patella and tendon was necessarily delayed.

Not all of the reports gave the period of immobilization, but of the 316 cases in which this question was answered the average period was 4.17 weeks. Among these 16 had only a compression bandage after operation, and 67 had 2 weeks or less immobilization. The period of immobilization varied with the seriousness of the injury and complications. Some surgeons, using stainless steel wire and other nonabsorbent, or slowly absorbent, suture material, believed that immo-

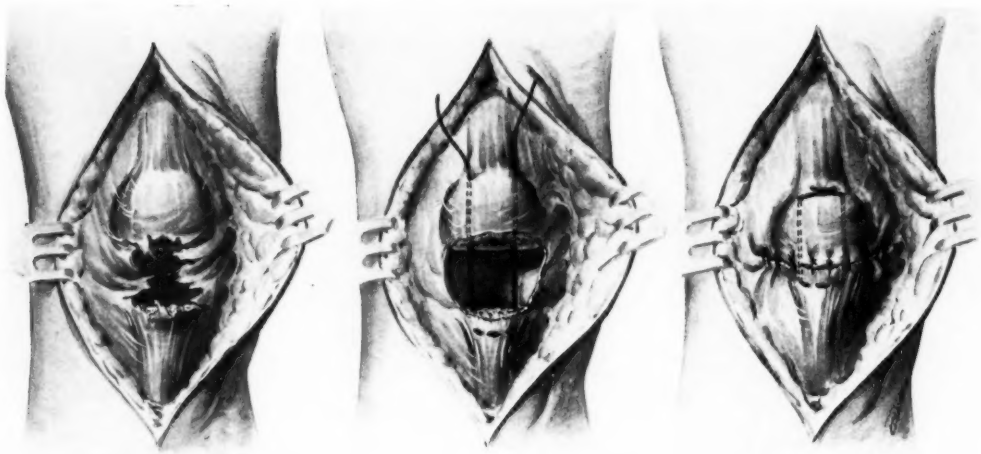

Fig. 1. Fig. 2. Fig. 3.

Fig. 1. Fracture of lower portion of patella, with separation of fragments and shredding of tendon fibers between fragments. Longitudinal semilunar incision. Skin flap reflected. Patellar region exposed.

Fig. 2. Small lower fragment removed. Shredded tendon fibers cut off. Edges of fractured patella smoothed. Drill holes identified as they pass through substance of patella, with kangaroo tendon suture in place. Heavy chromic catgut or stainless steel wire may be used.

Fig. 3. Lower patellar tendon drawn snugly against patellar fragment and kangaroo suture tied securely. Capsule and tendon structure closed.

bilization was not of major importance and that the suture and compression bandage were sufficient.

Severe complications and long bed confinement in 79 cases and conservative surgical judgment which kept patients off their feet in perhaps an equal number more, raised the average time before walking was allowed to 5 weeks. Contrast this to the 75 who were allowed to walk within 2 weeks and the 76 within 3 weeks, and it will appear reasonable that without complications to interfere, restricted flexion with early weight-bearing prevents atrophy and gives confidence, both of which are essential to a good result.

The average loss of time from work was 9.9 weeks for the 268 cases reported upon. Of this total number there were 189 fractures of the patella having no complications that had an average of 8.3 weeks loss of time. There were 79 cases with complications whose average loss of time from work was 14 weeks. There were students, clerks, teachers, and many others who were away from work only a short time. On the other hand, those engaged in more active occupations had a longer period of disability. Liability and compensation insurance, as well as various types of psychosis, often entered into this picture. Further, one must remember that 78 of these patients were between 50 and 60 years of age and 62 others were over 60 years of age. These fractures, when the patient is past middle age, require maximum healing and rehabilitation time.

In the consideration of the subject of disability of any impaired part of the body there is such a tremendous personal equation that must be taken into account, in connection with every opinion, that one must be guarded in the estimation of percentages. There may be a slight quadriceps weakness which in one individual is in nowise disabling, while for another it would constitute a considerable disability. Likewise, one might have extensive loss of normal flexion and have relatively little disability for almost any type of labor.

Four hundred and thirty-three reported with respect to disability: 350 were reported with no disability, leaving 83 cases with partial disabilities. Of these 83 cases 72 had disabilities under 15 per cent, which left only 11 cases with disabilities above 15 per cent. Among the 83 cases with disability there were 61 who had complicating injuries, disease, or infection that contributed to the estimation of their partial permanent disability. Of a total series of 433 cases this left only 22 patients with fractures of the patella without complications who had disabilities. In spite of disabilities up to 15 per cent in several cases, the results were spoken of as excellent,

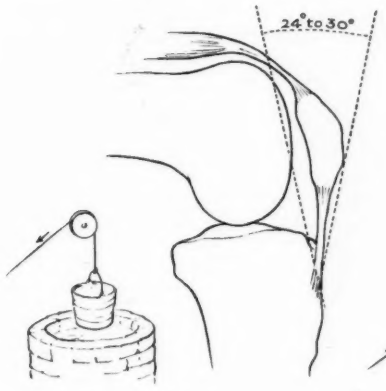

Fig. 4.

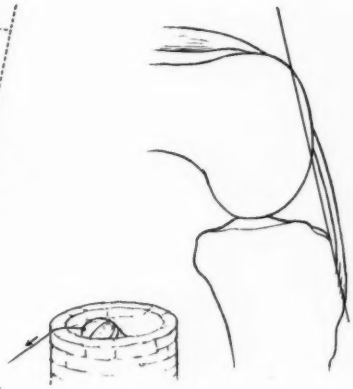

Fig. 5.

Figs. 4 and 5. The patella by carrying the quadriceps tendon away from the femoral condyles increases the leverage action of that muscle and lessens the effort required for extension. The removal of the patella decreases this leverage action—by an angle of 24 to 30 degrees—and greater effort is required to extend the leg. The principle of the patella action is similar to the lessened effort exerted when a bucket of water is drawn up over a pulley rather than when it is dragged over the edges of the well.

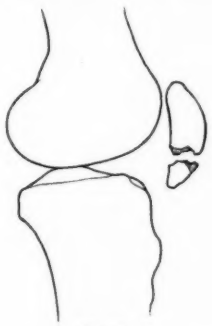

Fig. 6.

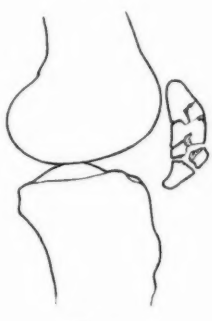

Fig. 7.

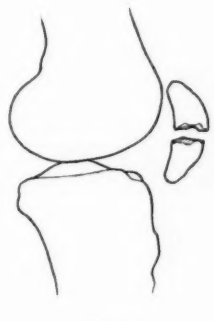

Fig. 8.

Figs. 6, 7, and 8. Types of fracture of the patella in which removal of all but one fragment and plastic repair of the tendon is particularly indicated.
Fig. 6. The small single fragment should be removed.
Fig. 7. The comminuted fragments should be removed.
Fig. 8. The lower fragment of transverse fracture should be removed.

splendid, and satisfactory. From a compensation insurance standpoint most fractures of the patella, or arthrotomies, leave a disability that must be considered in making a settlement, while a year later the impairment of function will be negligible.

It is interesting to note that in this series there were 56 compound fractures of the patella, and about half of these (26) had disabilities. Of the 26 cases 10 had complicating injuries, which left 16 uncomplicated compound fractures of the patella with disability. Fifteen of the 26 patients had a disability between 5 and 15 per cent and 8 had more than 15 per cent disability. In addition to these there were 3 compound fractures with admitted disability in which percentage was unestimated. This left 30 compound fractures of the patella with no disability.

Among the conditions incident to this operation that contributed to disabilities were several to which I wish to direct some attention:

First, post-operative infections: There were 4 of these and no explanation or reason was given for them. Three were serious and long disabling with 50, 30 and 25 per cent disabilities. The

Figs. 9, left, and 10. A severe comminuted fracture of the patella received while the patient, who is a sheriff, was in pursuit of a criminal. The comminuted lower fragments were removed, the irregularities of the fractured surface of the upper fragment were smoothed off and the lower patellar tendon was sutured to the upper fragment. In 8 weeks he returned to assume his full duty.

Fig. 10. Roentgenogram taken 2 years later. He has no limitation of function.

other case healed with little disability, 15 per cent. This is a low percentage when compared with the total number of operations in the series.

Second, complications that resulted from the use of heavy silk to unite the patellar tendon and fragment: In from 3 to 6 months after this procedure was followed in 6 cases an aseptic abscess formed. A minor operation for removal of the silk resulted in rapid healing. However, 3 of these patients had 5, 5, and 10 per cent disabilities. The 3 others had no ill effects except the discomfort and delay in complete recovery of function.

Four patients had subsequent injuries which caused refracture of the tendon, but apparently no refracture of the bone. A second repair did not cause any disability in these patients. In another case, the patellar fragment refractured; more fragments were removed and the tendon repaired with no disability resulting.

There were 10 bilateral fractures of the patella in this series. Four of these were associated with complications which contributed to disabilities in one of the extremities. Although the 6 others were severe injuries, there was no evidence that any disability followed the repair.

There were 15 cases with distinct weakness of full extension. Roentgenograms in such cases usually show the patella riding high on the condyles. This, we believe, is due to stretching of tendon substance or insecure approximation of the fragment to the tendon. Hoyt believes that the tourniquet may contribute to this, as a similar weakness occurs after other operative procedures in which a thigh tourniquet is used.

Hoyt and Fortin have noted some regenerative changes with no interference with function. At least calcium is laid down, giving the appearance of an abnormally large patella. This may be an ossifying hematoma. E. H. O'Donoghue reports a case of massive changes following wiring. Freiberg has seen similar hypertrophic changes after reapproximation of fragments. Could it be that the wire plays a part in stimulating the calcium deposit in a resolving blood clot? Never having used wire in this procedure and not having seen this phenomenon, I am at a loss to explain it.

Many have noted, among the advantages of this operation for the removal of fragments, the fact that there was no hypertrophy or abnormal enlargement of the patella.

OPERATIVE TECHNIQUE

My operative technique has varied but little from the original description (Figs. 1, 2, 3). However, in the course of this investigation there

have been several valuable suggestions and modifications for this procedure. All of them aim toward accomplishing and restoring better and more secure apposition of the opposing tendon-bone ends. Hoyt and O'Donoghue suggested wire as a suture through, or around, the bone fragment and the opposing tendon. Carter preferred a braided wire to a single wire. We have not yet tried stainless steel wire, but the many interesting and satisfactory results from its use would lead me to feel that there was considerable virtue in its security. As yet in none of these cases, in many of which patients were operated upon over 2 years ago, has it been necessary to remove the wire. Therefore, the wire apparently did not cause irritation with functional activity.

Contraction of the quadriceps has led occasionally to difficulty in reapposition of the fragment and tendon. The low tourniquet often contributes to this. We have found that a traction suture through the patella helped in bringing the tissues together. However, Stern states that adequate relaxation is accomplished by the use of either a spinal anesthesia or an extensive infiltration with one-half of one per cent novocain directly into the bellies of the quadriceps muscles, which makes it much easier to oppose the fragment and the tendon.

Prince, in his April, 1940, letter to the Orthopedic Correspondence Club, modified the technique not only by suture of the tendon to the fragment, but also by embedding the upper end of the tendon under the periosteum of the upper portion of the fragment. Stern has modified this still further. He also bores holes from above obliquely downward in the patellar fragment, so that they come out on the fractured surface just in front of the articulating portion. The suture material is introduced into the patellar tendon about an inch below the upper end, and then the tendon is brought into contact with the patellar fragment from the lower border across the fractured base and up over the top of the patella. Here, after the method of Prince, the upper end of the tendon is embedded under the periosteum of the patellar fragment.

These modifications may add to the better union and healing of the repaired patellar tendon, and have the virtue of bringing the remaining patella substance down farther on the condyles, which is so essential to the strength of the quadriceps action. A factor of technique which we believe of extreme importance to the restoration of good function, is the plastic repair of the capsule and ligamentous substance, which is usually torn, on either side of the patella.

Among those who submitted cases were 11 surgeons who reported 10 to 39 cases, inclusive, and 24 surgeons who reported 5 to 10 cases inclusive; or a total of 35 surgeons with considerable experience with this procedure. The largest groups reported were: Boyd, 39 cases; Hoyt, 24 cases; and Dillehunt et al., 19 cases; each with generally rather gratifying results.

CONCLUSIONS

Bear in mind that this is not a comparative evaluation of the various approaches to the treatment of fractures of the patella, but rather a study of a large group of cases in which a single operative principle has been applied. The conclusions are not my own but are the expression of the averages, clinical data, and opinions of those who furnished the cases. However, they verify convictions held ever since I recommended this procedure.

1. Fracture of the patella is common in middle life and seldom occurs among the young and aged.

2. It occurs in males more than twice as often as in females.

3. Comminuted fractures are twice as frequent as any other.

4. Compound fractures deserve the same consideration here as such fractures elsewhere.

5. The more familiar the operator becomes with this technique the earlier the fracture comes to surgical repair.

6. If there is extensive damage to integument and underlying tissues many prefer to delay operation (average 3.5 days) and allow a "tissue comeback."

7. This fracture is often associated with other complicating injuries that influence the ultimate outcome.

8. Early weight-bearing with restricted flexion should be encouraged (1½ to 3 weeks), provided complications do not interfere.

9. Loss of time away from work is directly proportionate to the severity of the injury and complications; 8 weeks for uncomplicated fractures and 14 weeks for complicated fractures.

10. There were but 22 fractures that were not complicated by other injuries that had disability. This number is only 5 per cent of the total cases completely studied. In none of these was the disability over 15 per cent. The average was 7.5 per cent, while those with complications had an average of about 16.5 per cent of function.

11. This large sesamoid has an important functional value to the knee joint, particularly when fully flexed (Figs. 4 and 5), in that it elevates the

extensor tendon above the condyles and away from the center of knee joint action in an acute angle. Removal of the patella brings the tendon closer to the center of knee joint motion in an obtuse angle, dragging the tendon across the broad surface of the condyles and thereby lessening the pulley action which the patella offers while extending the knee from the full flexed position.

12. The low bone reparative qualities of the patella would seem to indicate that it is essentially a part of a soft tissue motor mechanism. When fractured the problem of bone healing should be eliminated in favor of restoring the former important physical relationship of this sesamoid to the function of the knee.

13. Even a fragment of a patella forms a tremendous protection to the large exposed condyles of the femur in case of future accident.

14. The loss of a patella leaves an asymmetry of the knees.

15. Any effort to treat fracture of the patella which fails to restore whenever possible the normal functional integrity of the knee is not to be recommended; except that there is a distinct place for excision of the patella. First, in severely comminuted fractures in which there is no suitable fragment to anchor the opposing tendon to; second, in severe compound fractures that come late to surgery and are potentially complicated by infection; third, in the face of complicating degenerative arthritis and fracture. I do not believe one should consider excision as a first line of offense but as a reserve procedure to be used when complicating factors prevent the opportunity of establishing the normal integrity of the knee joint.

16. It is my opinion, as the result of this study, that in treating fractures of the patella the principle of removing all fragments except one pole of the patella (upper or lower) and firmly uniting it to the opposing tendon substance, after the technique described or by its modifications, offers the most satisfactory solution to this problem, in that it restores the cosmetic functional integrity and protective mechanism necessary to the normal knee. Further, it reduces the problem from one in which an effort is made to obtain a union in fragments of bone that have little osteogenic property to one in which only union of soft tissue is involved, without the loss of fulcrum stability of the patella, or buffer protection to the exposed condyles of the femur. By accomplishing this the period and amount of disability is reduced.

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COMPLICATIONS OF RADIOTHERAPY IN CANCER OF THE CERVIX

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THIS subject divides itself into two separate phases: (1) avoidable complications, i.e., those which arise as a result of an irradiation which, according to present standards, must be regarded as incorrect; and, (2) unavoidable complications, i.e., those which occur in spite of the application of what appears to be a correct irradiation.

The question at once arises as to what extent there is actually agreement upon the best methods of irradiation in cervical cancer. A careful consideration of this question permits the statement that after many years of uncertainty there have gradually crystallized certain broad and basic principles upon which there is today little disagreement. Although a wide variation exists in the technical details with which radium and x-rays are administered in the different cancer centers of the world, it is equally true that the ultimate results in good hands have shown strikingly little variation. This is due undoubtedly, to the strict observance of the principles and basic technique in spite of the variations in detail.

An understanding of the basic principles of radiation therapy in cervical cancer leads to complete agreement upon the main errors and pitfalls to be avoided in order to eliminate the complications which may be designated as *avoidable*.

Of all the radiotherapeutic procedures at our command, it may be said that the radiation treatment of cervical cancer is more nearly standardized than the radiotherapy of any other neoplasm, with the exception of skin cancer. This statement should not be taken to indicate that an exactly similar treatment is suitable for all cases. This is obviously not the case, but we can at least separate the cases into groups to each of which certain general methods can be applied.

The radiation treatment of cervical cancer consists of (1) intracavitary application of radium into the cervical canal and vagina, and (2) external radiation by means of x-rays or telecurietherapy. These two procedures, intracavitary radiation and external radiation, constitute integral parts of the procedure. Combined as a rule, one or the other method may be used exclusively. The sequence of these two procedures varies.

From the Chicago Tumor Institute.

Occlusion of the cervical canal. Before the complications which occur as the result of radiation are discussed, it is necessary to mention one condition which renders it difficult and sometimes impossible to introduce radium safely into the cervical canal, namely, occlusion of the canal by the growth. The danger of perforation in an effort to locate the cervical canal under these circumstances is well known. Experience has demonstrated the importance of avoiding this danger. This can be accomplished by initiating the treatment with external and vaginal radiation. The regression of the lesion following these procedures, with rare exceptions, results in a disappearance of the occlusion so that the cervical canal can be located without undue trauma and with no danger of perforation. As will be pointed out later, the use of external and vaginal radiation before manipulation of the canal is an important factor in diminishing or eliminating the most important of all complications—*infection*.

Injury to skin and subcutaneous tissues. Injuries to these tissues are best discussed together as, due to their proximity, injury of one must necessarily affect the other. Early injury to the skin consists of an "epidermite" which expresses itself as a moist denuded surface caused by a complete loss of the superficial layers of the epidermis. Late skin injury consists of telangiectasis, atrophy and, in extreme cases, ulceration.

The production of a moist epidermite should be avoided. It can be avoided by protracting the total duration of treatment to 5 or 6 weeks and adhering to the other principles of adequate filtration, limited surface areas, and low intensity. By adhering to these factors, the late skin injuries are also avoided.

Connective tissue damage, including injury to blood vessels, exhibits itself in the form of edema. This may appear within 24 hours of treatment or it may occur later during the radiation. Edema is one of the most important and helpful clinical signs in radiation therapy. It

indicates with fine precision that the normal tissues are unable to tolerate the intensity of the radiation that is being administered. Appearance of this sign is an indication for immediate reduction of the intensity of treatment or of the size of the field.

Injury to blood. The intracavitary application of radium is not complicated by any noteworthy injury to the blood elements and with rare exceptions the same holds true for external radiation. Lavedan and others have proved that treatment with the most intense methods of external radiation with radium as well as x-rays results only in a slight and temporary leucopenia followed by restoration to normal within a short period after the completion of treatment.

In the writer's experience the white blood cells of a small proportion of patients have a special sensitivity to radiation. I estimate the incidence as less than 5 per cent. In these cases the first few exposures result in an unusual diminution of the leucocytes, sometimes necessitating an interruption of treatment. With these rare exceptions, no serious or permanent damage to the blood forming organs is encountered following the fractional method of radiation.

Wintz admits that under certain conditions with the massive dose treatment severe blood changes finally leading to death cannot be totally avoided, but he believes that this risk must be taken in dealing with a lethal disease. In view of the favorable results of the fractional method of treatment, this risk does not seem justified.

The general apprehension regarding the dangers of injury to the blood forming organs accompanying massive radiation for cancer of the cervix is not supported by the most authentic evidence. All difficulties can be eliminated by avoiding the single massive radiation and by identifying the occasional patient with hypersensitivity of the white blood cells.

Injury to bladder. Injury to the bladder as a result of radiation in cervical cancer is uncommon if the treatment is given with reasonable precision. Serious damage to the bladder can occur only as a result of faulty radiation. A mild irritation of the bladder mucosa may become evident during treatment; the symptoms, however, generally disappear within a short period. Small superficial erosions of the bladder mucosa are sometimes observed on cystoscopic examination soon after intracavitary radiation. These lesions are said to be more common than has been generally supposed. They apparently heal within a short time and probably result in no serious or permanent damage. On the whole, bladder injury does not constitute a serious problem in the radiotherapy of cervical cancer.

Injury to rectum. The rectal mucous membrane is certainly one of the most, if not the most, sensitive tissues in the body to radiation. This fact, combined with the proximity of the rectum to the radium foci placed against the cervical lesion exposes the rectum to possible radiation injuries. Before the dangers associated with the uses of radium were adequately recognized, serious rectal damage often resulting in rectovaginal fistula was not uncommon. Today this complication is extremely rare. It must be noted that advanced stages of the disease untreated result in rectovaginal fistula in a small but definite proportion of cases, so that the presence of this condition does not necessarily indicate an incorrect irradiation.

Radiation effects upon the rectal mucous membrane result in definite clinical signs which vary in degree in proportion to the intensity of the radiation. The first and mildest reaction consists of a watery diarrhea without abdominal pain, with two to four liquid stools daily. These signs develop frequently during the beginning of the third week of external radiation when a little less than half of the treatment has been completed (4000 r. units or 150,000 mg. hrs.). This reaction naturally develops somewhat earlier in some patients. It constitutes a highly important clinical sign in that it indicates that the level of tolerance has been reached. A reaction of this degree does not require any changes in the radiation with the exception of reducing the size of the skin portal. The importance of making this one change can hardly be overemphasized.

If the rectal reaction becomes more severe, resulting in six to eight stools daily accompanied by colic-like pain, the indication is that the radiation is too intense. Under these circumstances either the daily dose must be reduced or the size of the field diminished or the treatment must be discontinued for several days or longer.

A profuse, severe diarrhea accompanied by colic-like pain is due to overdosage and should be avoided. Healy has directed attention to severe intestinal reactions occurring toward the end of the radiation and simulating the clinical picture of acute appendicitis.

Late postradiation sclerosis of pelvic tissues. Late sclerosis of the pelvic tissues may occur years after intensive radiation for cancer of the cervix. This state may be accompanied by occlusion of the vagina and cervix followed by pyometra, vaginal sclerosis, rectal obstruction, and occlusion of the ureters followed by pyelonephro-

sis or pyelonephritis. Regaud and Hermet have made a study of this late complication. They have described them as tumor formations usually located in one side of the pelvis and frequently involving the rectum, uterus, and bladder. In the beginning they are comparatively soft and lack the induration of a true recurrence. The contour is diffuse and the mass is painful to the touch. In one group of cases a closed pyometra with periuterine edema and diffuse parametrial inflammation simulates a local recurrence.

The diagnosis of these lesions may be exceedingly difficult. Such lesions may persist for many years before they disappear. A pyometra can be excluded by careful exploration of the cervical canal. In the other forms a differential diagnosis between postradiation sclerosis and recurrence is finally established only by the course of the disease.

I have encountered several cases in which mild palliative radiation was given for suspected late parametrial recurrences. The patients were discharged with an apparently hopeless prognosis. Several years later information has reached me that these patients are alive and well. There can be little doubt that these are examples of pelvic sclerosis and not recurrent carcinoma. The importance of recognizing this possibility is obvious and one should avoid giving a hopeless prognosis in the face of this possibility.

Postradiation intestinal obstruction resulting from benign stricture of intestine. This complication, although rare, is of the greatest importance. The writer has encountered two examples. Jones of Cleveland has reported 7 cases. Unless this possibility is considered, a diagnosis of recurrence is usually made. The clinical picture is classically that of intestinal obstruction. Jones has made the following observations:

"In 520 patients having cervical carcinoma who received radiation therapy there have been seven known cases of benign stricture of the intestine caused by obstruction which might easily have been construed as, or confused with, metastatic deposits. In five the obstruction was in a movable segment of the sigmoid and in two in the small intestine. Since similar methods of therapy are in general use, it seems probable that the incidence of the lesion is greater than is surmised, and if similar cases have been attributed to metastasis in the past, the mortality statistics relating to metastasis from cervical carcinoma are open to question. The intestinal obstruction developed in the seven patients from eight months to eight years after radiation therapy for cervical carcinoma. If the condition actually is a benign stricture caused by irradiation, it is obvious that additional roentgen treatment would only aggravate the condition and hasten the end. Therefore, a patient in whom unusual abdominal symptoms are present, particularly if they simulate intestinal obstruction, may have a stricture of the intestine and may be restored to normal health by resection of the colon.

"Before attributing this disability to metastasis, thorough re-examination by sigmoidoscopic and roentgenographic studies should be made to eliminate the possibility of this curable complication. Strictures in the small intestine are difficult to visualize unless the obstruction is practically complete. Barium in large amounts is inadvisable, and therefore, exploratory operation is warranted, especially in patients in whom there is no evidence of recurring carcinoma in the pelvis."[1]

Localized infection. Before the more serious and sometimes fatal generalized infections are discussed, brief reference will be made to the less serious infections which remain localized and from which the patient generally recovers. These may be divided into three groups:

1. *Early pyometra* due to occlusion of the cervical canal and appearing toward the end or within several weeks after radiation. This complication should always be considered and recognized as early as possible. Dilatation of the cervical canal and drainage frequently terminates this complication.

2. *Late pyometra* occurs from one to several years after treatment. The condition has to be differentiated from recurrence. The treatment is the same as for early pyometra. Occurring long after treatment, the diagnosis is more likely to be missed.

3. *Late infectious parametritis.* This complication arises usually one to three years after radiation treatment. It may be due to a reactivation of an old latent infection or to a new infection which becomes localized in tissues of a lowered resistance. This inflammatory complication must be differentiated from recurrent cancerous disease.

Localized and generalized infection during irradiation of cervical cancer. Infection during the process of irradiation is by far the most important complication associated with the radiotherapy of cancer of the cervix, the 2 per cent mortality charged against this procedure being due almost exclusively to the activation of hemolytic streptococci by the radiation. What are the circumstances under which this serious event occurs and how can it be avoided?

The incidence of hemolytic streptococci in cervical cancer is variously reported by different authors. Dehler reports that most cancers of the cervix contain streptococci and that over two-thirds of these are hemolytic. Clauberg, however, found nonhemolytic streptococci in 97 of 122 cases of streptococcic infection in cervical cancer. Philipp considers that hemolytic streptococci are the most commonly encountered organisms as well as the most virulent, although not all hemolytic streptococci are virulent.

In an effort to determine the virulence of the micro-organisms, Ruge devised a clinical test which has been amplified by Philipp. The Ruge-Philipp test determines the ability of the patient's micro-organisms to grow in a medium containing the patient's own blood. If the bac-

[1] Jones, T. E. Abstracted J. Am. M. Ass., 1935, 104:1854.

teria grow and multiply they are considered virulent. If they fail to grow or if they diminish in number they are considered of uncertain virulence. With this classification it was found that radiation treatment in the presence of a virulent streptococci resulted in 1 death (2 per cent). One patient developed severe complications and 48 had a smooth convalescence. Of 22 carriers of virulent streptococci 5, or *19 per cent*, died, 8 showed severe complications and 13 showed a smooth convalescence.

Many procedures have been advocated to combat this complication. Antiseptic douches, hypertonic salt solutions, copper salts, vaccines, autovaccination, and antistreptococcus serum have been recommended. A chemical known as rubaizol has been tried in the Curie Institute. None of these procedures have succeeded in effectively eliminating this complication.

Baclesse reports that among 44 cases of advanced carcinoma of the cervix treated intensively between 1922 and 1927 by external radiation, 7, or 16 per cent, died during treatment of infectious complications; whereas between the years 1928 and 1930 only 1 of 19 patients died of infection, 5 per cent. This author is probably correct in attributing the difference to an improvement in the technique and distribution of the radiation. It would seem from this evidence and other data that cautious, well distributed radiation diminishes the danger of infectious complications.

Since the introduction of sulphanilamide and its derivatives, several reports have appeared in the literature indicating their value in the treatment of these infections. In 1938 Goff reported a striking result in a pelvic cellulitis complicating radium treatment of a carcinoma of the cervix. He used sulphanilamide. In 1939 Bowing and Fricke reported the cases of 3 patients treated by sulphanilamide with excellent results.

SUMMARY

1. Most of the complications associated with the radiation treatment of cervical cancer are due to a faulty technique and are avoidable.

2. Edema of the skin and irritation of the rectal mucosa are two important signs indicating that the limits of tolerance have been reached. These signs, particularly the latter, should be carefully looked for and used as guides to the intensity of treatment. Careful attention to these signs at once obviates most of the avoidable complications.

3. Postradiation pyometra and sclerosis of the pelvic tissues occurring one to several years after treatment may simulate recurrent cancer so closely that a differential diagnosis is impossible. This source of error should be considered in rendering a prognosis and planning treatment in this group of cases.

4. Signs of intestinal obstruction appearing months or years after irradiation of cervical cancer should raise the suspicion of benign stricture of the intestine.

5. Infection constitutes a notable exception. This complication is largely unavoidable. The activation of latent hemolytic streptococci is a real danger and is associated with 1 to 2 per cent mortality. Virulent hemolytic streptococci are probably less frequent in early lesions.

6. A bacteriological examination should be made in every case before treatment as the infected cases require special attention.

7. An effort should be made to combat the infection by the best methods of anti-streptococcic therapy. Sulphanilamide has been used with considerable success.

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THE SIGNIFICANCE OF THE VENOUS CIRCULATION ABOUT THE ELBOW IN THE PATHOMECHANICS OF VOLKMANN'S CONTRACTURE

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THE concept that venous obstruction plays an important rôle in the mechanogenesis of Volkmann's contracture of the upper extremity has been premised, in great part, on the belief that the venous communication between the deep and superficial venous systems in the elbow region is a single venous channel and is susceptible to compression, as by a subfascial hematoma, within the confines of the antecubital compartment. The anatomical facts to be related in this investigation indicate that the venous communications between the deep and superficial networks are numerous and that the collateral system is widespread and well protected. This adds further evidence that the concept of venous obstruction as an important factor in the causation of Volkmann's deformity is untenable.

ANATOMICAL CONSIDERATIONS

The venous patterns about the elbow region, in the lower arm and in the upper forearm, were recorded by the writer from a study of 67 upper extremities—34 left and 33 right—in 34 human male cadavers, of which 19 were colored and 15 were white, and with ages varying from 22 to 85 years with an average age of 57 years. Anatomical dissections of the venous network in the upper extremities of 10 additional adult human male cadavers were made by the writer, following roentgenographic studies of the venous circulation with a radiopaque medium—30 per cent aqueous solution of sodium iodide.

The patterns of the superficial veins of the upper extremity have been investigated extensively and reported by Berry and Newton, Okamato, and Charles. The observations in the present study were confined to the deep venous systems and their communications. In the hand and forearm the fetal type persists throughout life and the superficial veins are dominant; in the arm and axilla the deep veins are most important. With rare exceptions the deep veins of the arm, forearm and hand in each case are satellites of the arteries, and each artery is accompanied by two veins.

Brachial veins. The brachial veins were most commonly two in number, the vein medial in position being larger than the vein located lateral to the accompanying brachial artery. At their origin from the radial and ulnar veins in the region of the elbow, they were often represented by a complex venous network that enveloped the brachial artery. The brachial veins received muscular branches from the biceps and brachialis anticus muscles, the veins accompanying the deep brachial artery, the internal and external collateral veins, and, occasionally, the circumflex veins; and they joined, separately or as one, the basilic vein to form the axillary vein at or about the level of the lower border of the teres major or subscapularis muscles. In some instances the axillary vein appeared to be a continuation of one of the brachial veins, usually the medial; in others, it appeared to be a continuation of the basilic vein. Asymmetry in the anatomical arrangement of these veins on both sides of the same cadaver was eight times more frequent than symmetry of their arrangement. In a few specimens, the brachial veins were represented by a single vein. Occasionally, they were poorly developed, the basilic receiving most of the deep venous return of the arm. In such cases not infrequently the medial or internal collateral vein (accompanying the inferior ulnar collateral artery) was very well developed and ascended along the brachial artery to terminate in the basilic vein, instead of one of the brachial veins as it usually does. In one specimen both brachial veins emptied into the deep brachial veins; in another, they terminated in a large medial collateral vein. The more common arrangements are illustrated in Figures 2 to 8.

Radial and ulnar veins. The radial and ulnar veins, the ulnar being usually the larger, joined within the antecubital fossa to form the brachial veins. The ulnar veins received the anterior and posterior interosseous veins deep to the pronator

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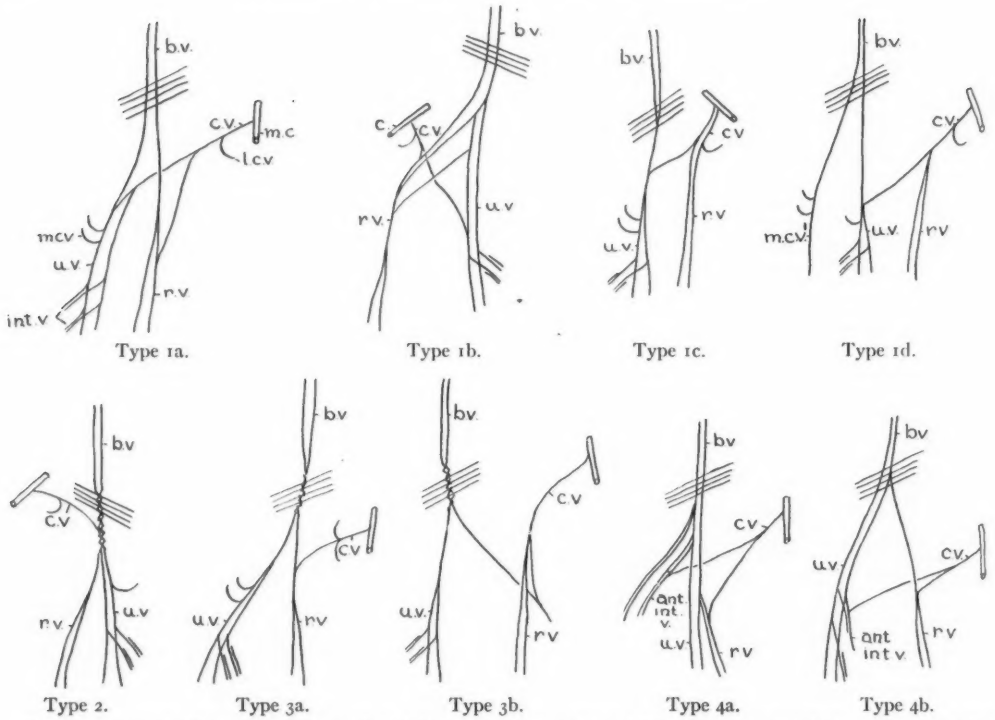

Fig. 1. Diagrammatic representations of variations in the formation of the communicating vein of the elbow in 67 upper extremities of 34 human cadavers. The incidence was as follows: type 1a occurred in 16 cadavers bilaterally and in 28 cadavers unilaterally; types 1b, 1c, 1d and 2, each in 1 cadaver unilaterally; type 3a, in 3 cadavers unilaterally; type 3b, in 1 cadaver unilaterally; type 4a, in 1 cadaver unilaterally and in 2 cadavers bilaterally; and type 4b, in 1 cadaver bilaterally. *b.v.*, brachial veins; *r.v.*, radial veins; *u.v.*, ulnar veins; *int.v.*, interosseous veins (anterior and posterior); *c.v.*, communicating vein of elbow; *c.*, cephalic vein; *m.c.*, median cubital vein; *l.c.v.*, lateral condylar branches; *m.c.v.*, medial condylar branches; *m.c.v.*[1], medial collateral vein. The obliquely parallel lines represent the relative position and course of the fibers of the lacertus fibrosus.

teres and flexor digitorum sublimis muscles and medial to the bicipital tendon. The venous patterns at this juncture varied considerably (Figs. 1 to 8).

High formation of the radial and ulnar arteries from the brachial artery in the upper or middle thirds of the arm was present bilaterally in 2 and unilaterally in 5 cadavers, while in one specimen the radial and ulnar arteries arose directly by division of the axillary artery. In these instances the radial and ulnar veins ascended in the arm and either terminated separately in the basilic vein or joined just prior to doing so (Fig. 3). In one specimen in which there was a high division of the brachial artery, the radial veins terminated in the cephalic vein, while the ulnar veins ascended in the arm to end in the basilic vein (Fig. 1, Type 3b).

COLLATERAL VENOUS SYSTEMS ABOUT THE ELBOW REGION

1. *Communicating vein of the elbow* (Figs. 1 to 8). The communicating vein of the elbow was always avalvular, but the valves of the deep and superficial veins were so placed as to require the blood to flow from the depth to the surface. It terminated in the cephalic vein, above or below the origin of the median cubital vein, or in the median cubital vein, close to the origin of the latter from the cephalic vein, or, occasionally, into both veins. In Figure 1 the formation of the communicating vein has been grouped broadly into four types: In the first type, the most frequent, this vein received branches from the radial and ulnar veins; in the second type the communicating vein arose from the venous plexus formed by the juncture of the radial and ulnar

veins; in the third type this vein received a communication only from the radial veins; and in the fourth type it was formed by branches from the anterior interosseous and radial veins. In all types the communicating vein received additional branches from the veins draining the lateral condylar muscles. Symmetry of the venous pattern in this region on both sides of the same cadaver was slightly more frequent than asymmetry.

In this investigation there were observed 3 distinct avalvular collateral veins or venous networks in the elbow region, in addition to the so called communicating vein (Figs. 2 to 8). That there are in addition to these 4 communications, other collateral systems present about the elbow region, which are too delicate to delineate from gross dissections, is evidenced by the complex networks visualized by means of a radiopaque medium (Figs. 7a and 8a).

2. A large communication was almost invariably present between the ulnar veins and one of the brachial veins or the basilic vein, by way of the medial collateral vein that lay ventral to the trochlea and brachialis anticus muscle and deep to the flexor group of muscles arising from the medial humeral condyle (Figs. 2, 3, 4, 6, 7, and 8).

3. A less constant communication arose from one of the lateral condylar veins, which pierced the triceps muscle substance and coursed posteriorly along with the radial nerve in the radial sulcus, joining the deep brachial veins (Figs. 2, 3, 5, 7, and 8).

4. A communication, the least frequent of all, arose from the ulnar or medial collateral veins, passed behind the internal condyle of the humerus in relation with the ulnar nerve, meeting the veins which accompanied the superior ulnar collateral artery, and terminating in the basilic vein (Figs. 7 and 8).

ROENTGENOGRAPHIC STUDIES WITH RADIOPAQUE MEDIUM

How effectual these collateral systems may be in transferring blood from below to above the elbow region was illustrated by roentgenography following the injection of a radiopaque solution (30 per cent sodium iodide) into the upper extremities of 10 cadavers.

In some of the specimens the brachial veins alone were ligated just above the elbow region. The solution of sodium iodide was injected into one of the radial or ulnar veins, and it appeared immediately in the arm above the site of ligation (Fig. 2). In these instances all of the communicating systems about the elbow region were intact.

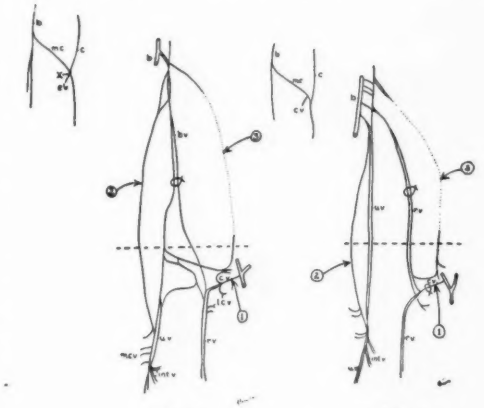

Fig. 2. Fig. 3.

Fig. 2. Scheme of (a) the superficial and (b) the deep veins and communicating systems *1*, *2*, and *3* (see text) of the elbow region. In this specimen the brachial veins were ligated above the elbow region but this did not interrupt the proximal flow of a radiopaque medium in the arm. *b.v.*, brachial veins; *r.v.*, radial veins; *u.v.*, ulnar veins; *int.v.*, interosseous veins (anterior and posterior); *b.*, basilic vein; *c.*, cephalic vein; *m.c.*, median cubital vein; *c.v.*, communicating vein of the elbow (*1*). The interrupted horizontal line represents the level of the elbow joint.

Fig. 3. Scheme of (a) the superficial and (b) the deep veins and communicating systems of the elbow region in a specimen with high division of the brachial artery in the upper third of the arm. Ligatures about the radial veins (which lay superficial to the ulnar veins) and the communicating vein of the elbow failed to interrupt the proximal flow of a radiopaque medium in the arm. *b.v.*, brachial veins; *r.v.*, radial veins; *u.v.*, ulnar veins; *int.v.*, interosseous veins (anterior and posterior); *b.*, basilic vein; *c*, cephalic vein; *m.c.*, median cubital vein; *c.v.*, communicating vein of the elbow (*1*). The interrupted horizontal line represents the level of the elbow joint.

In 10 specimens the communicating vein of the elbow was ligated just distal to its termination in the cephalic or median cubital veins, and the brachial veins were ligated just above the site of their formation, through very small incisions. The contrast medium was injected via one of the ulnar or radial veins, which was ligated just distal to the cannula, and the specimen was roentgenographed during the injection. The solution, despite these ligations, immediately entered and coursed up the arm in every instance, as noted in the roentgenograms (Figs. 4a, 5a, 6a, 7a and 8a), and by the immediate escape of the fluid (colored for purposes of recognition) from the cut surface of the proximal end of the specimen.

EVALUATION

It is generally accepted that external constriction is not essential for the development of Volk-

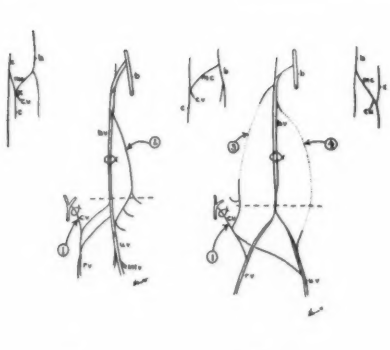

Fig. 4.

Fig. 5.

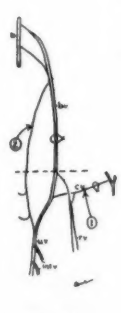

Fig. 6.

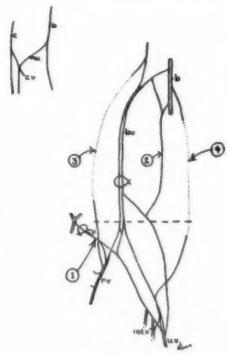

Fig. 7.

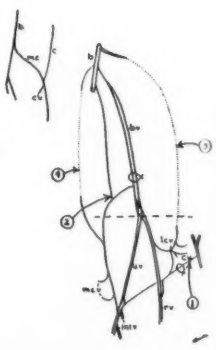

Fig. 8.

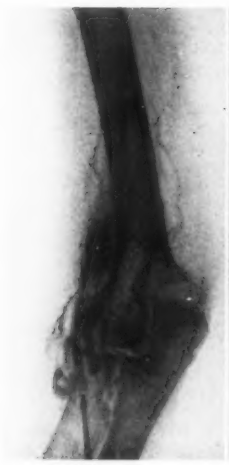

Fig. 4a.

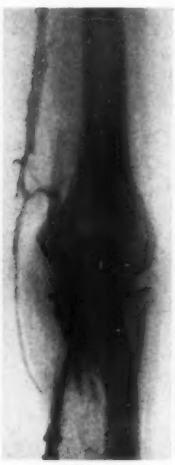

Fig. 5a.

Fig. 6a.

Fig. 7a.

Fig. 8a.

Fig. 4. This figure (as Figures 5, 6, 7, and 8) is a diagrammatic representation of (a) the superficial veins and (b) the deep veins and communicating systems *1*, *2*, *3* and/or *4* of the elbow region of a cadaver specimen. The brachial veins were ligated above the elbow joint and the communicating vein of the elbow was ligated just prior to its entrance into the superficial system at point *X*. The failure of these ligations to interfere with the proximal flow of a radiopaque fluid in the arm is illustrated in the corresponding Figure 4a. (Figures 5a, 6a, 7a and 8a correspond to figures 5, 6, 7 and 8). *b.v.*, brachial veins; *r.v.*, radial veins; *u.v.*, ulnar veins; *int.v.*, interosseous veins (anterior and posterior); *b.*, basilic vein; *c.*, cephalic vein; *m.c.*, median cubital vein; *c.v.*, communicating vein of the elbow (*1*). The interrupted horizontal line represents the level of the elbow joint.

mann's contracture and that a fracture need not be present (Hill and Brooks). Although peripheral nerve lesions may complicate the clinical picture, they are not constant and are not as a rule anatomically defined.

The protagonists of the concept of venous obstruction as an important factor in the etiology of Volkmann's contracture, emphasize the experimental evidence of Brooks (2), Middleton (17), and Wertheimer, Dechaume and Frieh, who produced a condition resembling ischemic contracture of muscle by sudden venous occlusion. They suggest that the fundamental pathomechanics of this condition are: abnormal pressure conditions—by a subfascial hematoma—in a limited space—the antecubital compartment — containing muscles and surrounded by resistant fascia and bone, and *drained by a peculiar anatomical arrangement that favors obstruction*. Middleton (16, 17) has discussed this anatomical arrangement in the elbow region; he suggests that a venous plexus with a diameter of about 2 centimeters drains the deep

structures of the entire forearm. This concept is supported by descriptions of the venous network of the elbow region in most anatomical textbooks and has been accepted as factual by many writers on the subject of Volkmann's contracture (Jones and Lovett, 14; Meehan, Garber).

There is increasing evidence, however, that arterial obstruction rather than venous obstruction plays a significant rôle in the etiology of this deformity.

1. Contractures of limbs in experimental animals were observed to occur following the production of arterial obstructive lesions, by Von Nario, Brooks, Johnson and Kirtley, 3; Wilson; and Griffiths, 10. It was noted by Jepson, and by Burman and Sutro that venous stasis alone was insufficient to produce permanent contractures of the limbs, and that, in addition, proximal constriction of the soft tissues was necessary.

2. Exploration in cases involving the upper extremity in the acute or threatening stage failed to reveal evidence of subfascial hematoma in the antecubital fossa. The muscle bellies were found to be engorged and discolored, but this was more common in the brachialis anticus muscle than in the forearm flexor muscles. There were subcutaneous extravasations and small hematoma-formation about the fracture site but no occlusion of the main veins could be demonstrated. In almost all of the arms explored, there were lesions affecting the brachial artery—vasospasm, incarceration between bony fragments, angulation, laceration or tear. In some arms in which the injured portion of the brachial artery was resected, there was evidence of injury to the adventitia or media or to both of these layers of the resected arterial segment (Griffiths, 10; Jones, 13; Plewes).

3. Volkmann's contracture has followed proved instances of arterial occlusion. Griffiths (9, 10) noted that in 3 cases in a series of 20, patients operated upon for arterial embolism, developed typical Volkmann's contracture—one of the forearm and hand, and two of the calf and foot—despite successful restoration of the arterial circulation. Similar contractures following arterial obstruction in the lower extremity have been reported by Grieg and by Dieulafé.

4. The evidence derived from the anatomical material in this investigation, that a sufficient collateral venous circulation exists normally in the elbow region, well protected between muscle planes and external to the confines of the antecubital fossa, indicates that the theory of Middleton, on which the protagonists of the concept of venous obstruction have relied to a considerable extent, is untenable.

CONCLUSIONS

The belief that arterial obstruction plays a more significant rôle than venous obstruction in the pathogenesis of Volkmann's contracture is receiving increasing clinical and experimental support. To this is added evidence that the theory of Middleton, on which the protagonists of the concept of venous obstruction have relied, is untenable. The anatomical studies in this investigation indicate that a widespread venous anastomosis exists normally in the elbow region, well protected between muscle planes and external to the confines of the antecubital space.

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REINFORCEMENT OF THE DELTOID LIGAMENT FOR PRONATED FLAT FOOT

Inversion Fasciodesis of Os Calcis

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SOLUTION of the problem of flat foot has been sought by many in both surgical and nonsurgical procedures. The latter, based mainly on the belief that acquired flat foot is a consequence of muscle inadequacy, have led to the elaboration of a system of therapy which depends on foot braces, shoe modifications, and a ritual of muscle exercises. In our experience, even when religiously prosecuted, these have proved futile in the cure of the truly pronated flat foot. In the main, the failures have been attributed to lack of co-operation, but the fact that pronation may occur even in the presence of a well developed musculature seems to have been overlooked. Despite this, and possibly in deference to the natural reluctance of parents to submit their children to surgery for relief of what appears, at outset, to be a relatively innocuous affliction, the conservative treatment has been maintained and by some extolled.

That the affliction is not so innocuous, nor the conservative treatment so effectual, is indicated by the variety of surgical procedures which have been devised from time to time. Moreover, the very multiplicity of the suggestions is, in itself, proof that no single method of surgery has thus far adequately solved the problem. Practically almost every important bone, muscle, ligament, and joint of the tarsus has been surgically attacked. Generally speaking, the procedures employed fall into two categories—the anterior operations directed toward correction of the depressed longitudinal arch, and the posterior directed toward inversion of the pronated heel.

That one or another of the anterior group of operations may successfully correct a true planus need not be denied. But whether the correction of the anterior deformity can effect a correction of the posterior deformity by pressure from below may be seriously doubted. It is, in fact, to the failure of such efforts that various procedures intended to supinate or invert the everted hind foot owe their origin. On the whole, the anterior group of operations has proved to be more successful in restoring the longitudinal arch than the posterior group has been in overcoming the pronation of the heel. In retrospect, it appears that these results might have been expected because of the failure to correct the pronation deformity at the apex of its angle of deviation; the subastragalar joint. The realization of the importance of the proper handling of this joint above that of any of the other tarsal joints in the treatment of pronated feet seems to be the very basis of the good results obtained by Clark and later by Zadek.

In part, some of the difficulty which has been encountered is due to the fact that two anatomically different situations have been grouped together as a single clinical entity. Anatomically, the foot is a unit composed of a number of separate segments. Physiologically, the foot consists of two separate organs, the hind foot and the fore foot. *Pes planus* describes a flattening of the longitudinal arch, that is, a change in anatomical relationship between fore foot and hind foot, and *pes valgus*, a rotation of the hind foot in relation to the longitudinal axis of the superimposed leg. Pes plano-valgus describes the combined form.

Obviously the cure of pes planus must be by surgical means which act across the mediotarsal joints to stabilize the fore foot in relation to the hind foot; while the cure of pes valgus must be effected across the subastragalar joint so as to stabilize the hind foot in relation to the leg. In the absence of a stabilized hind foot, it is useless to discuss the problem of the longitudinal arch.

By comparison with the lower or anthropoid forms, in which the arch is depressed and the os calcis everted, the human hind foot is supinated. Naturally, the development of the longitudinal arch has been associated with this inversion of the heel, and *active supination* has been considered the mechanism of its accomplishment.

Largely under the influence of Keith, who expressed the opinion that "with the maintenance of the normal arch, ligaments are not directly concerned" but that "the longitudinal arch of the foot is dependent on properly and automatically balanced muscles in leg and foot," the belief has been propagated that the cause of flat foot is a muscle weakness. Even Morton, who stated

From the Hospital for Joint Diseases.

categorically that "the term 'balance' as applied to foot structure does not refer to muscle activity but to the arrangement of the bones and ligaments which furnish a stable base upon which body weight can be supported with the least demand for muscular exertion and propelled evenly balanced upon the lever axis," admitted the importance of the flexors of the foot in elevation of the arch and in rotation of the os calcis. Though he denied the significance of the supinating mechanism, Morton concluded that the longitudinal arch appeared in consequence of the leverage action in a foot in which the body weight had shifted from the outer toward the inner side of the foot. As a consequence of such teaching, the nonsurgical treatment has been designed to increase the power of existing invertors, while the surgical treatment has been devised to supplement their action either by fusion or by actual muscle transplantation.

More recent observations upon the embryology of the human foot cast interesting light upon the etiology of flat foot. Boehm showed that at about the end of the third intrauterine month, the foot is held in a position of marked supination, adduction, and internal rotation, i.e., in the position of extreme equino-cavo-varus. Thereafter the supination tends to recede and though still present at birth, the appearance of the adult foot is acquired slowly and as a result of *pronation*. This general impression was confirmed by Boeker in his study of the prints of infantile feet. At birth, the foot is held in supination and the sole of the foot, as well as the big toe, preserves many of the characteristics of the prehensile foot. When the infant begins to walk, but little weight is carried by the big toe which is still prehensile and is not used for progression. The thrust is balanced on the outer side and the fore foot acts as the steadying force while the heel is raised from the ground. At the age of 2½ years, most of the weight is still over outer side of foot and the longitudinal arch appears flat. By the age of 10 the body weight has moved toward the inner side, the big toe gives evidence of greater weight bearing, and the longitudinal arch is fairly well formed. By 14 years, with increasing weight and medial shift of the thrust, the big toe transmits a larger proportion of the body weight and a still higher adult type of arch is present.

In fact, it appears that active pronation is the fundamental process and that the development of the longitudinal arch is the result of the conversion of the fully supinated foot into one characterized by relative pronation of the fore foot. In any flexible foot it can readily be demonstrated that with the heel fixed, relative pronation of the fore foot invariably results in an increase in the height of the longitudinal arch. Indeed, it was in the hope of accomplishing exactly this effect that the "skew" elevation of inner border of heel and outer border of the sole of the shoe was devised.

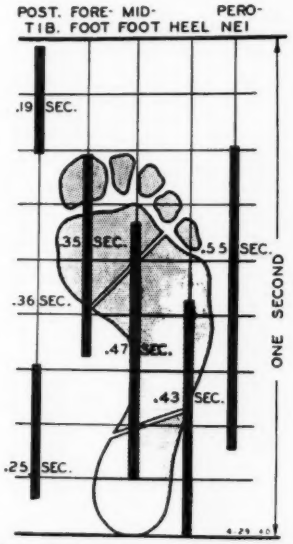

Fig. 1. Average sequence and duration of weight bearing on heel, midfoot, and forefoot as related to sequence and duration of contraction of the posterior tibial and peroneal muscles. (From Schwartz, loc. cit.)

It is in the realization of the importance of the fore foot pronating mechanism that the studies by Schwartz acquire added biological significance.

"The heel receives and supports body weight for 0.436 seconds. The posterior tibial muscle contracts simultaneously with placement of the heel on the floor, but its duration of contraction is only 36.1 per cent of the total stance phase of the step, 0.694 seconds; 57.5 per cent of the total time the heel is on the floor. Therefore it is evident that this short period of reflex function of the tibialis posticus does not prevent the foot from pronating while walking.

"This too early discontinuance of a positive force that could prevent pronation is accompanied by peroneal contraction which further provokes the characteristics of pronation in each step. The peronei begin to contract 0.166 seconds after the heel contacts the floor and continue to contract for 79.8 per cent of the stance phase of the step, as against 36.1 per cent previously stated for the posterior tibial" (Fig. 1).

Here again the relative importance of the pronating mechanism of the fore foot as contrasted with the supinating mechanism of the hind foot is demonstrated. Contrary to the general belief, it is the absence of active fore foot pronation rather than of active hind foot supination that leads to pes planus. Without a powerful pronat-

Fig. 2. Sagittal section. The heavily shaded line indicates the fascial graft.

ing force, the supinating counteraction of the ground against body weight leads to dorsal extension and supination of the first metatarsal with flattening of the arch and loss of the inner support of the foot tripod. (This is not uncommonly seen following peroneal transplantation in muscle balancing operations.)

But while the action of the peroneal muscles and the gravitational effect of body weight tend to pronate the *foot as a whole*, pronation of the fore foot alone can be accomplished only if some mechanism is provided by which the hind foot can be prevented from pronating. That the tibialis posticus plays a part in supinating the hind foot cannot be denied, but the relatively short period of its action indicates that the ultimate defense against pronation of the heel must be sought in the ligamentous structures whose anatomical function normally is the limitation of excessive motion. That this is the case is shown by the marked valgus which characterizes the stance in patients suffering from hypotonia. It is further substantiated by the high arch and supinated heel of the club foot as contrasted with low arch and pronated heel of patient with an avulsion fracture of tip of tibial malleolus.

These facts were clearly suggested by the elder Whitman in his discussion of weak feet. "At first glance, it may seem that the depression of the arch is the most noticeable peculiarity in a characteristic case of flat foot and that the popular name is, therefore, an appropriate one. On closer examination, however, it will appear that the foot is not flat because its 'keystone has sunk,' but that the lowered arch is caused by lateral displacement (abduction). . . . it has been stated that under normal conditions, in the act of passive weight bearing, the astragalus rotates downward and inward upon the os calcis, depressing its anterior and internal border until the movement is checked by the strong ligaments."

Clearly, the therapeutic indication is the restoration of the ligamentous support along the inner aspect of the ankle to check excessive pronation of the heel. As early as December, 1936, this was attempted by transplantation of the tibial insertion of the deltoid ligament. Though the procedure was successful in maintaining the varus of the heel, some limitation of ankle joint motion resulted, and this, combined with fear of injuring the epiphyseal cartilage in growing children, led to a search for another means of effecting a ligamentous check on excessive pronation of the heel. The key to the problem was suggested by a study of the normal deltoid ligament.

"The deltoid ligament is a strong, flat, triangular band attached above to the apex and anterior and posterior borders of the medial malleolus. It consists of two sets of fibers, superficial and deep. Of the superficial fibers, the most anterior (tibionavicular) pass forward, to be inserted into the tuberosity of the navicular bone and immediately behind this they blend with the medial margin of the plantar calcaneonavicular ligament; the middle (calcaneotibial) descends almost perpendicularly, to be inserted into the whole length of the sustentaculum tali of the calcaneous; the posterior fibers (posterior talotibial) pass backward and lateralward, to be attached to the inner side of the talus and to the prominent tubercle on its posterior surface, medial to the groove for the tendon of the flexor hallucis longus. The deep fibers (anterior talo tibial) are attached above to the tip of the malleolus and below to the medial surface of the talus" (Gray).

This ligament, by far stronger than the lateral ankle joint ligament, is obviously directed toward the prevention of external rotation of the hind foot. In this, it is supported by the powerful interosseous talocalcaneal ligament, whose fibers are so directed as to counteract any tendency toward eversion of the os calcis.

But the whole function of these ligaments is not only to act as a check to external rotation of the os calcis. If it were so, biomechanical stresses would have led to the development of the deltoid ligament in the plane of the internal malleolus. This is not the case. By far the larger part of the ligament fans out to be inserted much anterior to this plane. This makes it evident that this portion of the ligament develops in response to stresses which tend to roll the os calcis *outward* and *downward*. In other words, it appears that the upward and inward direction of the ligament

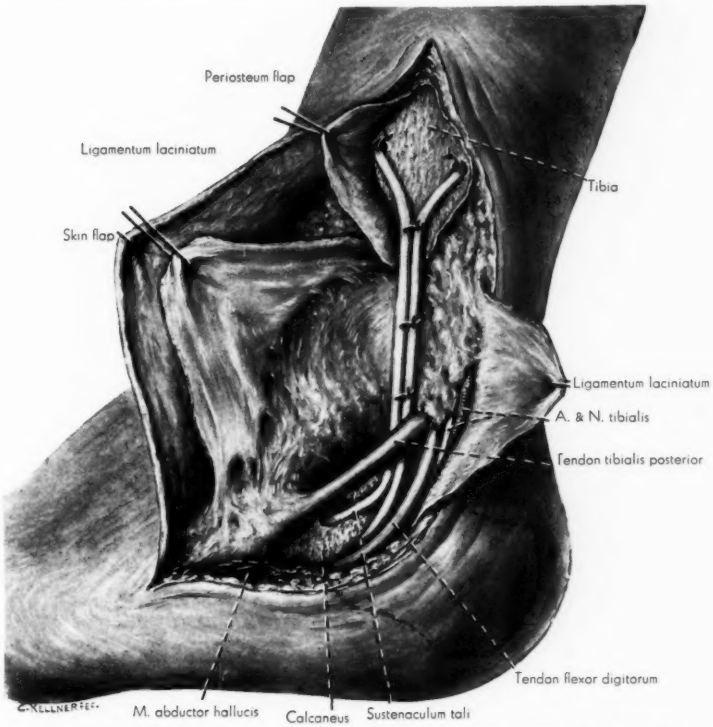

Fig. 3. The fascial graft *in situ*, seen from the medial aspect. When sufficient graft cannot be obtained, the anterior ascending arm may be dispensed with.

is to prevent exactly that malposition which is characteristic of the pronated hind foot.

To simulate this action of the deltoid ligament, to elevate and invert the os calcis, the following operative procedure has been devised. Under a tourniquet placed around the calf, a curved incision is made, extending from the scaphoid tubercle backward around the tip of the internal malleolus and then upward to a point about 3 inches above the malleolar tip. At a point sufficiently above the epiphyseal line, to prevent injury to the growing zone, the medial surface of the tibia is subperiosteally exposed. A tunnel, running anteroposteriorly, is made, beginning on the medial surface of the tibia, above the epiphyseal line. Through this, a guide suture is passed. The incision is opened so as to expose the abductor hallucis below and the tendon of the tibialis posticus in front. The sustentaculum tali is visualized between the tendons of the tibialis posticus and the flexor longus digitorum muscles. With a broad, blunt, periosteal elevator, all the tissues lying below the sustentaculum and posterior to the calcaneocuboid articulation are elevated, and a transverse calcaneal tunnel is drilled, so as to emerge on the lateral surface of the os calcis, in the region of the trochlear process. The guide suture previously passed through the tibia is now passed down along the inner aspect of the ankle, beneath the tendon of the tibialis posticus muscle, and around inferior surface of os calcis. A small external counter incision is made, and from without inward the graft is passed back through tunnel made in the calcaneus (Figs. 2, 3).

A small incision is now made over the fascia lata, at the lower portion of the thigh. With the fascial stripper, a long strip of fascia is removed subcutaneously and is passed through the drill holes, exactly along the course of the guide sutures. The heel is strongly supinated and the strands of the fascial graft are sutured to the bone and are then united to each other, if possible. The wound is closed in layers and a plaster-of-Paris boot is applied, with the foot in the maximum of inversion. Immobilization is maintained for a period of 6 weeks. Upon removal of the

Fig. 4. Case 1, before operation. Note the medial convexity of the Achilles tendon. On the lateral view, the prominent scaphoid tuberosity is clearly visible.

plaster, a well molded foot plate is prepared and patient is allowed to bear weight in wedged shoes.

Since the operation is intended solely for those cases in which excessive pronation has resulted from a loss of the restraining action of the deltoid ligament, it is clear that it should not be employed when the pronation is caused by bony deformity. Obviously, a valgus due to a malunited fracture of the lower end of the tibia is not amenable to correction by this procedure. It is essential, therefore, to determine, by roentgenograms of the ankle joint, that (1) the plane of the articular surface of the tibia is perpendicular to long axis of the bone; (2) the astragalus is held in its normal position by a well developed ankle mortise; and (3) there is no abnormality in the os calcis. If these facts can be established, the pronation may be attributed to a loss of deltoid ligament support.

Theoretically the operation is applicable to all such cases regardless of age. However, it would appear to be undesirable to attempt drilling of the os calcis before sufficient bone had been laid down to minimize the danger of interference with normal growth. Similarly, it would appear unwise to defer operation beyond the time when a physiological readjustment of the tarsal articulations might be reasonably expected. Quite arbitrarily, therefore, it is suggested that the optimum period for operative intervention is between the ages of 7 or 8 and 14 or 15 years.

The first of the cases treated by this method was operated upon in 1937. Usually a well formed arch in a thoroughly flexible foot has resulted. In general, the greater the supination of the hind foot, the higher has been the longitudinal arch. But even when the arch has not been completely restored, the elimination of pronation of the hind foot has been accompanied by a marked relief of symptoms. There is usually complete relief of pain and the sense of fatigue present before operation.

The following case reports present special points of interest.

Case 1. Ramos B., aged 9 years, was admitted to the hospital in August, 1940. At the age of 3, the child had been seen and treated at the hospital for bow-legs. He was brought to the hospital at the present time by his parents, who noted "prominent bones on the inner aspect of both feet." On examination it was noted that there was a marked valgus of both heels, especially the left, with pronation of both feet and flattening of the longitudinal arches (Fig. 4). At first it was thought the patient was suffering from accessory scaphoids or enlarged scaphoid tubercles, but x-ray examination showed no evidences of any abnormality in the scaphoid region. The patient was conse-

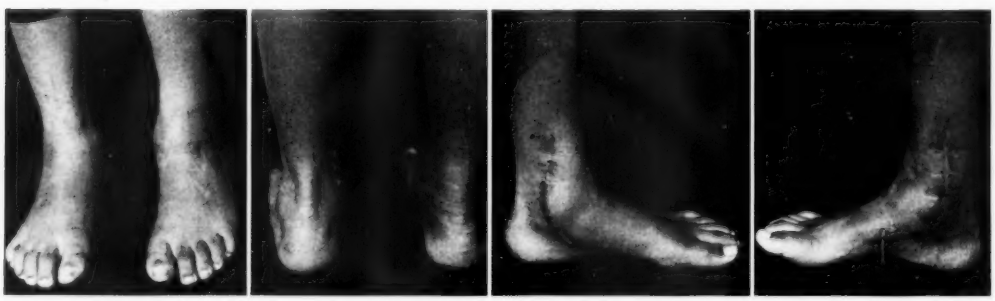

Fig. 5. Case 1, after operation. On right, the supination of the heel is greater than on the left. On lateral view, the arch on the right side is better than on left. The prominence of the scaphoid tuberosity has disappeared.

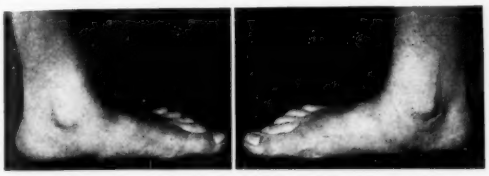

Fig. 6. Case 2. Lateral view before operation.

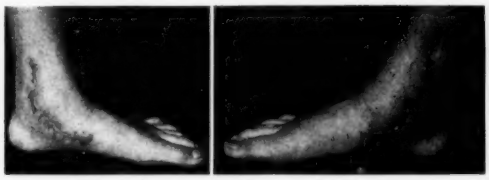

Fig. 7. Case 2. Lateral view after operation.

quently admitted to the hospital and on August 20, 1940, the right foot was operated upon; on September 3, 1940, the left foot was operated upon. The deltoid reconstruction operation described was performed on both sides, the heels being pulled into marked varus by means of fascial graft, and being maintained in this position by means of plaster-of-Paris boots for a period of 6 weeks. At the end of September, the plaster boots were removed and it was noted that the wounds had completely healed, but on the right side there was definite limitation of motion and evidence of a local inflammation. X-ray examination disclosed that this was due to some osteolytic lesion in internal malleolus.

This was, at first, thought to be due to pressure of the fascial graft against the underlying internal malleolus. However, the contour of the defect did not seem to be consistent with this interpretation, and re-examination of the preoperative x-ray films revealed some lesion which had been overlooked. Wet dressings were applied to the right leg, and in time the swelling subsided and a fair range of motion returned. On October 30, weight bearing was permitted, and shortly thereafter the patient was discharged from the hospital, walking in shoes with a wedging in the inner borders of the heels. On January 21, 1941, it was noted that both heels were in the neutral position. The longitudinal arches were well preserved and the prominence noted over the scaphoids had disappeared. The patient walked quite well, but on the right side some perimalleolar inflammation still persisted. On the left side, the range of motion at the ankle was excellent, on the right side, a slight residual limitation of motion persisted (Fig. 5). Under physical therapy, this swelling gradually diminished and the range of motion in the right ankle increased. In June, 1941, it was observed that well formed arches were present on both sides. The feet were quite flexible, gait was normal, and the patient made no complaints. The arch supports were discontinued, and patient permitted stock shoes with only small wedge along inner border of the heels. Up to present correction has been retained.

The second case proved of special interest because of the association of accessory scaphoids and markedly pronated heels. The accessory scaphoids caused no pressure symptoms and were neglected in the surgical procedure. The result obtained tended to confirm the opinion that the ligamentous repair was the essential element in the correction of the flat foot condition.

CASE 2. Mary R., aged 13 years, was brought to the hospital in the early part of September, 1940, because of flat feet and a painful prominence over the inner aspect of both feet which had been present for a period of about 2 years. Examination disclosed marked pronation of both heels, dropping of the longitudinal arches, and prominences over the scaphoids. The roentgenogram was reported as showing bilateral accessory scaphoids (Fig. 6). However, it was noted that when the heels were held in the varus position, the arches could be promptly restored. Because of this and despite the presence of the accessory scaphoids, it was felt that the pronation of the heels represented the primary deformity, and the operation here described was performed bilaterally. The postoperative convalescence was uneventful, and in the latter part of October, 1940, the plaster was removed. The wounds were found to be completely healed. The patient was fitted with Whitman plates and was then permitted to walk in wedged shoes. She was seen in December, 1940, at which time photographs (Fig. 7) were taken. The patient noted complete absence of symptoms and restoration of well formed longitudinal arches. Foot plates were discontinued, and up to the present the arches have remained elevated. The accessory scaphoids are still present but do not appear to cause the patient any discomfort.

The procedure here outlined would seem to have its special application in adolescent patients between the ages of 8 and 14 or 15 years, in whom excessive pronation of the heel persisted. In younger children, the operation would probably present greater difficulties and might be unnecessary. In older patients, the definitive establishment of the tarsal joints would probably vitiate the result. In the proper age group, the procedure has the merit of being completely extra-articular and of avoiding the danger of injury to the epiphyseal growth zone. Thus far, the feet operated upon have remained flexible, painless, and with well formed arches.

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VOLVULUS OF THE CECUM

Anatomical Factors in Its Etiology; Report of a Case

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VOLVULUS of the cecum, usually involving to some extent the proximal colon and terminal ileum, is generally regarded as one of the rare causes of intestinal obstruction. Yet, on the basis of incidence alone, cecal torsion deserves more than passing notice. Lenormant (1929) found that 3.4 per cent of his 88 cases of intestinal obstruction were due to a twist of the right colon. Jacobsen (1924), analyzing 53 cases, obtained a figure of 11.6 per cent. Pratt and Fallis (1927) state that 5 to 6 per cent of instances of ileus in the United States is caused by cecal torsion; this percentage—which, to the present authors, seems amazingly high—is challenged by Sweet (1935) who found only 1.2 per cent of 520 cases determined by this condition. Estimations of the proportion of cecal volvulus, as compared with volvulus of other locations, vary widely: Jacobsen (1924) avers that 31.6 per cent of all cases of volvulus are of the right colon; Guibé (cited by Sauvé and Lejeune, 1934), 17 per cent; Sweet (1935) 11.3 per cent.

There are other reasons for according this disorder serious consideration. Homans (1921) has noted that, while it is less common than sigmoid volvulus, it is surgically more important than the latter. Moreover, the mortality is high, exceeding 50 per cent.[1] The need for early diagnosis and immediate surgical intervention in the usual acute case is emphasized by Chalfant's (1921) figures: of 96 patients operated upon, 59 per cent died; of 23 not operated upon, all died. The significance of cecal volvulus is further heightened by the possibility that, in addition to the acute cases ordinarily reported, there exist instances of chronic partial torsion. Twyman (1923) has recorded an example of the latter, and considers it a diagnosable entity; such an opinion is supported by Corner and Sargent (1905), Pratt and Fallis (1927), and Grace (1938). In this connection, it is noteworthy that Beeger (1923), in a study of 69 patients, found volvulus complete in only 42 per cent. It is possible that there is some relationship between partial cecal torsion and that much disputed entity, *cecum mobile*. Finally, it is clinically important that partial cecal volvulus may produce symptoms like those of acute appendicitis. Pascalis (1929) states that he has attended several persons with suspected appendicitis who were found at laparotomy to have a twisted right colon; he believes that cecal volvulus must always be considered in the differential diagnosis of diseases presenting signs and symptoms in the right lower quadrant.

Contribution from the Northwestern University Medical School, Department of Surgery and Department of Anatomy (No. 352 from the latter). Portions of this paper were presented before the Chicago Surgical Society, April 4, 1941, and before the American Association of Anatomists, April 10, 1941 (Abstract, Anat. Rec., 1941, 79: No. 3, suppl. No. 2, 7, 1941).

[1]Corner and Sargent (1905) computed a fatality rate of 66 per cent in 57 cases of patients operated upon and not operated upon, collected from the literature; Chalfant (1921), a mortality figure of 67 per cent in 118 cases of patients operated upon and not operated upon; Beeger (1923), a death rate of 53 per cent in 69 cases of patients operated upon.

DEFINITION

It is not easy to formulate a definition of volvulus of the cecum. As will be seen, the abnormal anatomical freedom which permits the development of this disorder varies in degree. Therefore, volvulus, centering about the cecum runs the gamut from a twist of the isolated cecum to torsion involving all of the small intestine and most of the large. The designation "volvulus of the cecum" is misleading; most of the cases so named involve also a variable amount of the ascending colon and terminal ileum. The condition could better be termed "volvulus of the right colon," were not the present name so firmly entrenched. Gatellier, Moutier and Porcher (1931) have proposed that volvulus of the cecum be defined as a condition in which torsion is limited to the cecum, ascending colon, and terminal ileum. This forms a satisfactory entity on embryological and anatomical grounds, since the right colon is usually fixed in its upper reaches, no matter how defective may be the peritoneal attachments of the cecum and adjacent bowel. Clinically this definition serves to separate right colic torsion from sigmoidal volvulus, iliac volvulus, and total volvulus.

LITERATURE

The first report of a case of cecal volvulus was probably that of Rokitansky in 1841. Critical consideration of the

TABLE I.—GEOGRAPHICAL DISTRIBUTION 193 CASES (SINCE 1913)

Geographical Unit	No. of cases
North America	40
France	32
Eastern and Central Europe	31
Scandinavia	23
Germany	21
Italy	16
England	13
South America	7
Orient	4
Africa	3
Switzerland	2
Low Countries	2
	194

question appeared only with the publications by von Zoege-Manteuffel (1898). Since his time a literature has accumulated that is not only large but increasing, due at least in part to recent accessions in the medical periodicals of North America and Central Europe. No effort has been made here to assemble a complete tally of all the cases published, and bibliographic efforts have been confined principally to the years since 1913. Faltin in 1902 found 79 reported cases; Ekehorn, in 1904, 92; Bundschuh, in 1913, 110; Kunz in 1928, 155; Podlaha, in 1929, 168. Taking Bundschuh's (1913) review as a basis, a cursory search of the readily available sources has yielded 194 cases (including the current one) since the date of his report. The total of 304 recorded cases is without doubt incomplete. The geographical distribution of the 194 cases collected is of more than mere statistical interest, in view of the geographical aspects of the etiology of the disease, which will be discussed later. It also shows that the incidence in North America is relatively greater than is generally assumed (Table I).

ANATOMICAL FACTORS IN ETIOLOGY

It has been accepted from the beginning that torsion of the right colon depends on an abnormal degree of mobility of cecum and ascending colon; this would make cecal volvulus basically a congenital disease, Lynch (1933) listing it as the most important of the abnormalities of the colon which require surgery. The anomalous freedom of the right colon[1] has been almost universally conceded to be an embryological accident, failure of obliteration of the fetal right mesocolon with the consequent persistence of an adult mesentery, though von Thun (1913) has suggested that general enfeeblement of the abdominal organs and acquired enteroptosis might also play a part.[2]

[1]It must be noted that the normally "fixed" cecum is usually free enough to be lifted out of the wound in the process of performing an appendectomy. Flint (1921) believes that study of cadavers is misleading on this point. This normal mobility is clearly evidenced by the x-ray findings of Moody (1929). Engel (1857) ascertained that 70 per cent of ceca can be raised readily; Dreyer (1911) gives a figure of 67 per cent. The whole colon is much more mobile than many suppose; Barclay (1932), in fact, would have it shifting about the abdomen, under certain circumstances, in an "acrobatic manner." Carson (1926) is of the opinion that real fixation of the cecum is entirely abnormal. The mobility with which we are here concerned—that which allows of cecal volvulus—is of quite a different order than the normal freedom.

[2]There is one form of volvulus, usually considered rare, though Corner and Sargent (1905) think it may be common, which is regarded as acquired, not congenital. This is volvulus of the cecum alone about the long axis of the bowel. It can occur only in a cecum which has become secondarily pouched and distended. Pouching must be taken as an acquired cecal characteristic, for the fetal cecum is a tapering one which merges imperceptibly into the base of the appendix.

The sequence of events in the fetal abdominal cavity by which the colon gains its adult position and attachments is too well known to require detailed repetition here. It may be said, in brief, that the cecum gains its mature locus through the operation of three processes: rotation, which carries the originally left sided ascending colon across the abdomen; descent, by which the cecum sinks from a subhepatic situation into the right iliac fossa; fixation, whereby the right mesocolon is lost and the right colon made adherent to the posterior abdominal wall. Mobility of the cecum depends largely on the degree to which this last process extends. If fixation is incomplete, the cecocolon enjoys a greater or lesser amount of freedom of movement; it may retain its own proper mesentery, or, if the terminal ileum is loose, a common ileocecocolic mesentery may result. Descent is substantially complete by the eighth month of fetal life (Hertwig, 1902; Keith, 1910); the cecum has then attained its adult position. Fixation proceeds thereafter, but the final peritoneal relationships are not fully established until about 4 months after birth (Harvey, 1918). The possibility of hypofixation is balanced by that of hyperfixation, in which the process goes to excess, yielding an entirely retroperitoneal cecum, and spreading at times to involve the normally mobile terminal ileum. General hyperfixation, of course, precludes any possibility of cecal volvulus. However, hyperfixation is often local (Carslaw, 1928), the principal sites being the beginning of the transverse colon (by the duodenorenal ligament) and the hepatic flexure (by the right renocolic ligament), though it can occur anywhere on the ascending colon. Such a point of local hyperfixation, combined with looseness of the proximal large bowel, provides an anatomical situation obviously favorable for a cecal volvulus—there being a mobile segment and a fixed spot to act as a hub.

A right colon which has failed to gain normal stability by fusion of its mesocolon with the posterior parietes is, nonetheless, often protected by the formation of secondary supportive attachments. Such structures as Jackson's membrane, Lane's band, and various pericolic membranes are to be explained on such a congenital basis (Connell, 1913; Gray and Anderson, 1913; Munroe, 1926). Flint (1921) has often seen a band anchoring the otherwise free cecum laterally,

while it has been Coughlin's (1927) experience that Jackson's membrane is present only in patients possessing an ascending mesocolon. An embryological explanation of the origin of these abnormal retaining membranes is afforded by assuming persistence of Reid's (1911) "genito-mesenteric fold." However, Crotti (1930) would have it that if the cecum remains beneath the liver overlong, it acquires adhesions which persist even after fetal descent has taken place; such secondary bands, if unsuccessful in immobilizing the cecum, become a menace to its integrity, since they achieve the same result as would local hyperfixation; in fact, the two processes may be akin.

While the failure of fixation is the principal cause of right colic mobility, it must be recognized that nonrotation and nondescent may also play a lesser rôle; as early noted by Tandler (1897), the nonrotated or partially rotated cecum and the nondescended cecum are particularly likely to remain without effective fixation. The importance of these factors is indicated by the observation of Corner and Sargent (1905) that the left hypochondrium is the most common site of clinical cecal volvulus. Rixford (1920) and Carter (1938) report cases of complete nonrotation (left sided colon) with subsequent cecal volvulus; Bulman (1924) cites an instance of embryonic failure in the midgut torsion (giving an "heptatic flexure" in contact with the splenic) which suffered a cecal volvulus. Some other accidents in the colon's development may also result in a free cecum. Thus the unique case of Low and Hilderman (1940), in which there was true hyperrotation (400 degrees instead of the usual 270), possessed a *cecum mobile* on a mesentery; though there was no volvulus, it would have been anatomically possible. The rare occurrence of reversed rotation of the colon is evidently often followed by volvulus; 2 cases have been reported in which patients died of other causes (Hunter, 1922; Harvey, 1926), while 3 cases have been recorded in which patients developed a cecal volvulus (Dott, 1923; Donald, 1927; Holman, 1940).

ANATOMICAL OBSERVATIONS

Stimulated by growing surgical interest in the ileocecal region, many anatomical studies have been made of the iliac and colic peritoneal relationships, some of them specifically directed toward the problem of cecal mobility. The present authors feel justified in adding another to this list of reports for 3 reasons: first, previous authors have often not examined their patients in detail, being content to record some one feature; second, many series have been concerned with children rather than adults; third, most of the exhaustive studies have been conducted in Europe, there being no comparable works in this country.

The authors have examined 125 normal consecutive adult dissecting-room cadavers.[1] The mesenterial attachments of the cecum, ascending colon, and terminal ileum were critically studied, area of posterior fixation graphically mapped. In the records, however, no effort was made to distinguish between primary fixation and secondary attachments, or even between instances of common ileocecocolic mesentery and those with a right mesocolon but which lacked continuity with the mesentery of the terminal ileum. A classification was then devised and the specimens were placed in the selected categories. Classification of the variations in the peritoneal attachments of the ileocecal segment, incidentally, is not clear cut, since, in fitting cases into arbitrary types, the succession of almost imperceptible gradations in the extent of fixation must be disregarded. In Figure 1 are presented diagrams illustrating this classification, and showing the distribution of 125 specimens among its types; each sketch was prepared from a specimen representative of the class, and, in some instances, demonstrating the scope of divergence within a class. Figures 2 to 9 contain detailed drawings of individual cases.

In type I (see Fig. 1) the cecum is completely or almost completely fixed to the posterior wall, being in some cases retroperitoneal. Seven specimens, 5.6 per cent, fell into this group; Figure 5 shows such a cecum, and illustrates the characteristic tight adhesion. In 14 subjects, 11.2 per cent, the cecum is attached through a third or more of its posterior surface (type Ia). In 20 cadavers, or 16 per cent, type Ib, cecal adherence to the posterior abdominal wall, extending the length of the organ, is variably narrow, in some instances being a very short mesentery. Type II is made up of specimens having peritoneal attachment at the ileocecal junction with the cecum free; there are 21 of these, 16.8 per cent. In 3 bodies, 2.4 per cent, type IIa, the arrangement is complicated by tight adherence of the terminal ileum to the posterior wall; Figure 8, though not of a specimen belonging to type IIa, illustrates this type of fixation of the terminal small bowel. Ceca with a descending line of fixation beginning just above the ileocecal junction (type III)

[1]These were American whites and negroes, mostly males, constituting regular dissection material of the anatomical laboratories of the Northwestern University Medical School. All were prepared for student use by the phenolglycerin technique, which leaves the intestines almost as mobile as in life. Bodies with indications of intra-abdominal disease were rejected.

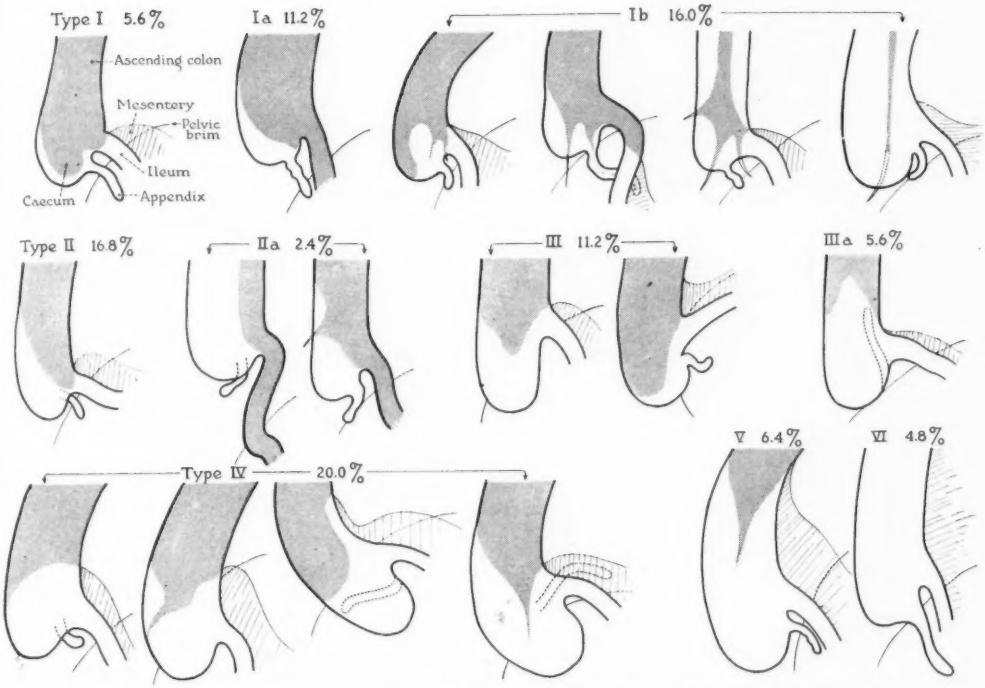

Fig. 1. Diagrammatic figures, based upon actual specimens, recording the range of ileocolic attachment in 125 consecutive adult specimens; for convenience types are indicated, the percentage occurrence of each type noted.

occur in 14 subjects (11.2 per cent). In type IIIa, the line of attachment ascends, leaving the cecum free; this arrangement obtains in 7 or 5.6 per cent. Figure 4 illustrates an example of type IIIa: a hyperdescended cecum hangs free in the true pelvis, with a line of attachment beginning just above the ileocecal junction and ascending colon without adhesion. In 25 instances, 20 per cent, type IV, this line of fixation is situated well above the ileocecal junction, though the cecum is sometimes fixed laterally by a descending line of fusion. In Figure 2 is pictured a cecum that falls into class IV. It is somewhat exceptional in that a redundant cecum, fixed in the iliac fossa, turned backward upon itself, to point upward and touch the liver (termed an "erect cecum"). Figure 3 illustrates another example of type IV, in which, however, there are two extra retaining bands. In type V, 8 subjects, 6.4 per cent, the cecum and much of the ascending colon are free of attachment to the posterior abdominal wall. Figure 6 is an example; there is a completely mobile cecum and ileum, as shown by the ease with which it could be retracted medially. The ascending colon is also without fixation throughout much of its length. Type VI, 6 subjects, 4.8 per cent, illustrates complete freedom of the whole right colon. Such cases have, to a greater or lesser extent, a common ileocecocolic mesentery.[1] Figure 8 shows an example of this type, further complicated by a retroperitoneal ileum which occupied the iliac fossa; such an attachment would provide a fulcrum for volvular movement. Figure 9 illustrates another instance of type VI; it demonstrates that embryonic failure in rotation and descent is the basis of malposition, the cecum here occupying the left hypochondrium.

The application of these anatomical observations to the question of cecal volvulus is obvious. Only those right colons free of adherence to the posterior parietes for at least a part of their length are subject to torsion. It is immediately

[1]Complete ileocolic *mesenterium commune* does not occur as frequently in most series. Keyes (1939) found it in 2 of 148 cadavers, 1.4 per cent; Treves (1885) in 2 of 100, 2 per cent; Wandel (1903) in only 1 per cent of 640 cases. Our criteria were perhaps more elastic, since we included all cadavers with a free ascending colon even if the hepatic flexure were adherent. Also, 1 of the 6 cadavers had a retroperitoneal ileum and another a very short ileal mesentery, so that actually only 4, 3.2 per cent, possessed a common mesentery.

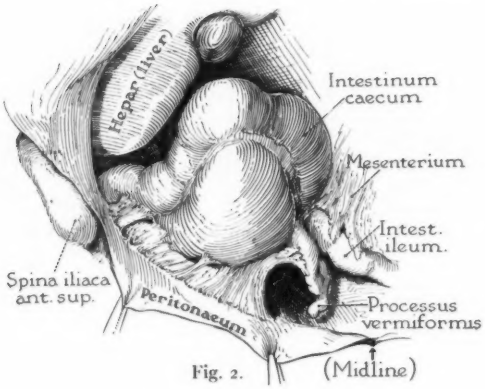

Fig. 2.

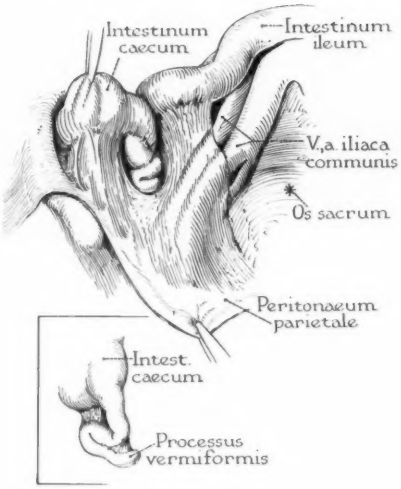

Fig. 5.

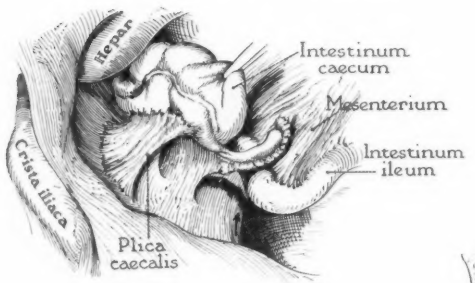

Fig. 3.

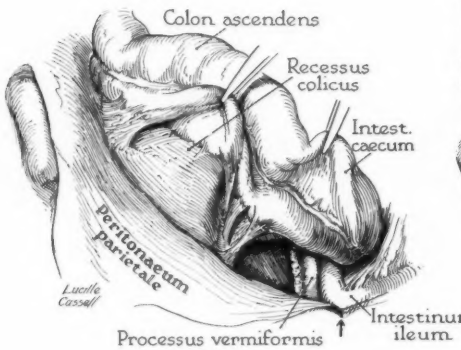

Fig. 4.

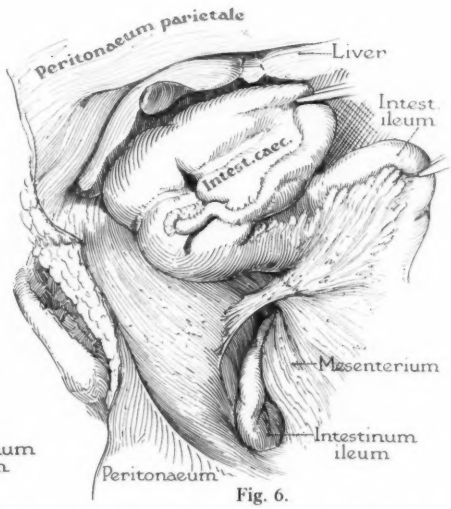

Fig. 6.

Figs. 2 to 6. Detailed drawings of cecal and related structures from selected specimens. Figs. 2 and 3, type IV; Fig. 4, type IIIa; Figs. 5 and 5a (same specimen), type I; Fig. 6, type V.

apparent that types I, Ia, and Ib are too firmly fixed to permit volvulus. Ceca of types II, IIa, and III also seem too securely moored to permit twisting, unless the cecum were to become greatly pouched. Even in the latter event, a fixed point for torsion would be a further requisite. In this particular class IIa would perhaps be predisposed to volvulus because of the presence of a well anchored ileum. Types IIIa and IV in some instances present ceca that could revolve were concomitant pouching and dilatation to occur; none of the specimens in these two categories

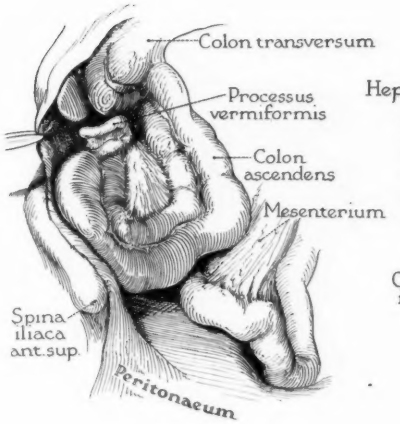

Fig. 7.

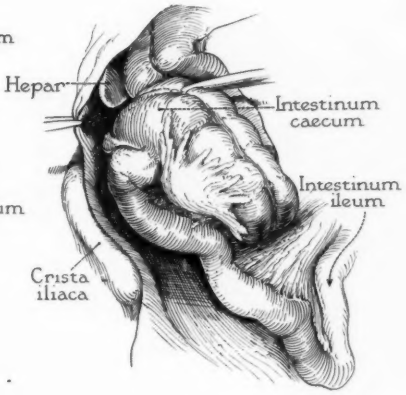

Fig. 7a.

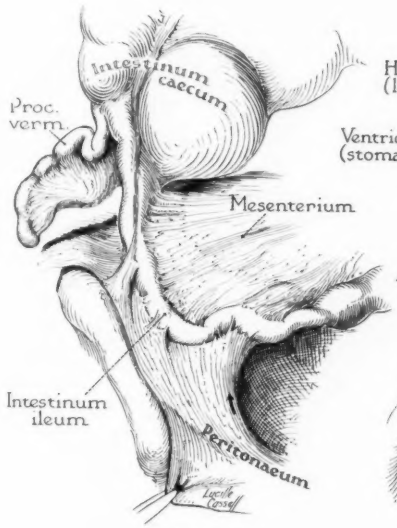

Fig. 8.

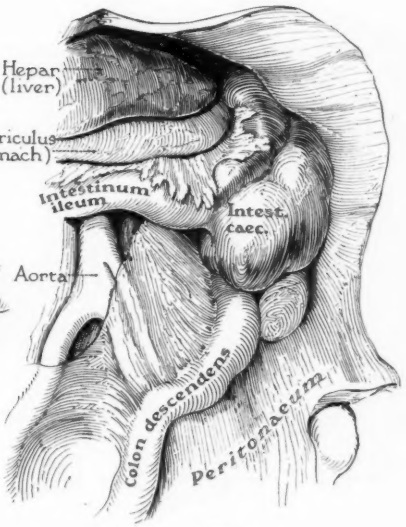

Fig. 9.

Figs. 7 to 9. Drawings of cecum, etc., continued. Figs. 7 and 7a (same specimen), type V; Figs. 8 and 9, type VI.

could be manipulated into a position of volvulus in the abdomen of the cadaver. On the other hand, types V and VI are certainly predisposed to torsion of the right colon; all of the examples of these two classes permitted such manipulation. Type V would seem to represent the ideal in predilection, since in members of this group the bowel is mobile and the ascending colon fixed at a single locus which could behave as a stable point around which the free segment could turn.[1] Three of the eight specimens of type V actually exhibited partial torsion. Figures 4, 7, and 7a illustrate a case in which the right colon had already been so rotated that the ileocecal junction

[1]It is significant that many reported cases of clinical volvulus of the cecum were observed to have a band securing the ascending colon and acting as the hub of the twist. Lehmann (1922) reported a case of cecal volvulus in the presence of a free cecum and a retroperitoneal ascending colon and was able to collect 6 other cases from the literature.

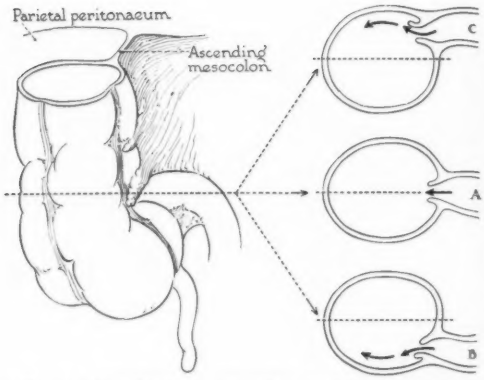

Fig. 10. Hypothetical explanation, recorded in diagrams, of the dependence of the direction in volvulus upon the plane of the ileocecal orifice; the direction of force would tend to initiate a clockwise turn (B) or counterclockwise movement (C) were the cecum turned from a coronal plane (A).

was on the lateral margin of the large intestine and the ileum passed behind the cecum, as shown by lifting the latter. Treves (1885) and Pernkopf (1928) reporting cases similar, regarded them merely as instances of unusual cecal position.

Types V and VI, together making up 11.2 per cent of the series, represent the percentage in which the right colon is physically able to undergo twisting. To this total perhaps should be added those which, if secondarily pouched, could revolve. If volvulus occurred in members of types V and VI, it would be truly congenital; volvulus in members of other classes would be, in a certain sense, acquired.

A comparison of our figures with those of other investigators is given in Table II. It should be noted that these data were collected in various ways (for the possibility of maneuvering the cecum into a position of volvulus; for the occurrence of right mesocolon, etc.). Some used cadavers, others autopsy material or radiographic records; some studies were carried out on children, others on adults. The figures in Table II are, therefore, not altogether comparable. It is significant that the incidence of ascending mesocolon runs over 20 per cent while that of extraordinarily mobile right colon is only 10 to 15 per cent—a fact that would indicate that a right colonic mesentery may be compensated for by secondary anchoring membranes. The present authors' figure of 11.2 per cent of ceca able to form a volvulus compares well with Engel's (1857) 10 per cent, Wandel's (1903) 10.3 per

Fig. 11. Roentgenogram of the authors' case, taken preoperatively after a barium enema. The cecum (at reader's lower left) is greatly dilated; arrows point to the ends of the small lumen within the twisted portion; through this lumen barium reached the terminal colon and cecum.

cent, Kantor and Schechter's (1934) 10.4 per cent, Treves' (1885) 11 per cent, Harvey's (1918) 13 per cent, Piersol's (1907) 14 per cent, Alglave's (1907) 15 per cent, and well also with von Thun's (1913) 19 per cent. The higher figures recorded by some workers possibly may be due to the inclusion of infants, or to the failure to regard secondary bands of attachment. All in all it would seem fair to say that some 10 to 15 per cent of adults are anatomically predisposed to cecal volvulus.[1]

In 1905 Kelly and Hurdon called attention to the fact that the terminal ileum may be firmly fixed, even retroperitoneal, instead of normally free. Since then others have reported on various features of such cases (Oelschlaegel, 1924; Benini,

[1]It should be noted here that anatomical information on peritoneal attachments of the ileocecocolic region are of service in other clinical matters than cecal volvulus. These observations are of obvious pertinence to the questions of *cecum mobile* and of the possible pathological effects of retroperitoneality of this area, as well as to such problems as abnormal location of the vermiform appendix, internal hernia and ileocecal intussusception, which latter both Lynch (1933) and Morley (1920) state to be dependent upon ileocecal nonfixation. The high incidence of intussusception in infancy no doubt bears a direct relation to the higher proportion of ileocecal hypofixation in the early years of life.

TABLE II.—MOBILITY OF CECUM AND RIGHT COLON

Author	Date	No.	Mobile No.	Per cent	Type of data	Description
Engel	1857	100	10	10	Cecum free	Adults
Treves	1885	100	11	11	Cecum free	Adults
Addison	1900	40	6	15	Ascending mesocolon	Adults
Wandel	1903	640	66	10.3	Able to twist	Adults
Alglave	1907	100	15	15	Cecum mobile	Adults
Piersol	1907	35	5	14	Cecum mobile	Children
Smith	1911	982	319	32.4	Ascending mesocolon	Infants
Dreicka		640		23	Ascending mesocolon	
Fallon	1913	100	22	22	Ascending mesocolon	Adults
von Thun	1913	388	72	19	Able to twist	All ages
Harvey	1918	105	14	13	Ascending mesocolon	Infants
Pirie	1920			20	Ascending mesocolon	Children
Bailey				25	Ascending mesocolon	
Begg				25	Ascending mesocolon	
Coughlin	1927	100	22	22	Ascending mesocolon	Adults
Kantor and Schechter	1934	383	40	10.4	Cecum mobile	X-ray study of adults
Authors	1941	125	14	11.2	Able to twist	Adults

TABLE III.—INCIDENCE OF FIXED TERMINAL ILEUM

Author	Date	No.	Fixed No.	Per cent	Description
Addison	1900	40	8	20	
Armstrong	1921	50	2	4	Cecum free
Alglave	1907	100	13	13	Cecum fixed in 8 per cent
Harvey	1918	105	9	8.6	
Leveuf	1914			10	Fetuses
Mollison and Cameron	1908	50	5	10	
Authors	1941	125	13	10.4	Adults. Cecum free in 5, fixed in 8.

1932; Piotet, 1934; LeVay, 1940). The importance of the fixed ileum in providing a point around which the right colon may swing to form a volvulus is noted in one of the cases of Sweet (1935); abnormalities of ileal attachment are stressed in this regard by McGowan and Dixon (1936). There have been a few studies on the percentage occurrence of fixed ileum, though the figures are at such variance as not to be very helpful (Table III); in these it is not generally indicated whether the cecum was free or fixed.[2] In our series, 13 subjects, 10.4 per cent, showed stable terminal ileum, whether retroperitoneal or bound down by extra bands; but only 5 of these, 4 per cent, were combined with a free cecum. The figure of 10.4 per cent compares well with the observations of previous authors, except for the low figure of Armstrong (1921) and the high one of Addison (1900).

No example of the rarer conditions (reversed rotation, left sided colon, hyperrotation, etc.), sometimes responsible for mobility of the right colon, was met with in the current study; nor was any case found in which the cecum and hepatic flexure were fixed and the right colon free and redundant between them. Volvulus of such a segment is noted by Homans (1921). This particular type resembles those cases in which sigmoid volvulus is due to a similarly redundant sector.

[2]Armstrong (1921) reported two cases of fixed ileum with mobile cecum; he notes that two similar cases were found in a survey of 50 bodies.

THE MECHANICS OF CECAL VOLVULUS

Much has been written on the mechanics of cecal volvulus, and many classifications have been proposed, of which perhaps the best are those of Treves (1900), Corner and Sargent (1905), Faltin (1902) and McGowan and Dixon (1936). However, it is felt that too much stress should not be laid on classifications and rigid mechanisms. The literature amply demonstrates the simple fact that right colic volvulus can involve a variable amount of bowel, and that it can occur in many ways, depending upon the anatomical relationships and the presence or absence of pathological adhesions. Thus a colon with a common ileocecocolic mesentery may turn about the superior mesenteric vessels as an axis; or, the opposite extreme, an isolated cecum may twist on itself—sometimes not obstructing the bowel, as in Makkas' (1929) case, in which the point of torsion was distal to the ileocecal junction. A locus of attachment on the ascending colon can act as the point of revolution and hence of obstruction, or a fixed terminal ileum can act in the same manner. If both the ascending colon and the ileum possess adherent areas, the intervening bowel can turn between them, if free, as shown in the patients discussed by Smith (1920) and Kirby (1929). A redundant loop of right colon with a narrow base can turn on itself after the fashion of a sigmoid volvulus, with obstruction of both the afferent and efferent limbs (Homans, 1921). Abnormal membranes or adhesions may further complicate the mechanism of volvulus, as in cases of adherent appendix (Nowland, 1925), of appendix fixed in the left pelvis (Cochrane,

1929) or even to the sacrum (Edwards, 1917). There are other rare and bizarre mechanisms, as for example, Wistinghausen's (1919) case in which the terminal ileum wrapped around the ascending colon to form a pedicled cecum that underwent torsion.

The direction of rotation of an ileocecal volvulus cannot be completely accounted for on anatomical grounds. Many assume that the direction of twist is almost always clockwise. However, as pointed out by Beeger (1923) and Graham (1926), direction depends upon how the clock is placed; and it is apparent from some descriptions and figures that not all authors have faced the hypothetical timepiece in the same direction. Beeger and Graham feel that the direction should be taken from an imaginary timepiece placed, dial upward, upon the patient's abdomen. Since many of the accounts in the literature are uninterpretable because of this confusion, no attempt has been made to compute the percentage of rotation in one direction or the other. Faltin (1902, 1903) found only 15 of 50 analyzed cases had a clockwise twist. Jacobsen (1924), reviewing 24 cases, found 50 per cent clockwise. Von Zoege-Manteuffel's original idea that the medial attachment of the mesentery accounts for the usual clockwise rotation must be held in abeyance. It seems more plausible, mechanically, for a free cecum to roll medialward on its mesentery than for it to turn counterclockwise beneath that structure. However, Dixon and Miller (1940) are of the opinion that cases with a common ileocecocolic mesentery twist in a counterclockwise direction, while the turn is more frequently clockwise if the colon distal to the cecum is fixed. It is possible that the position of the ileocecal junction, dorsal or ventral to a frontal plane through the long axis of the right colon, may be important, since the force of the ileal contents driven against the anterior or posterior wall of the cecum might be sufficient to give the impetus for rotation counterclockwise or clockwise, respectively (Fig. 10).

INCITING ETIOLOGY

Although the anatomical background of cecal volvulus can easily be demonstrated, the fact that there are so few cases of the disease indicates that the inciting etiology deserves careful examination. That the anatomical predisposition is not the sole basis is suggested by a number of facts. Thus, von Thun (1913) found a majority of cases of cecal mobility in children below 5 years; yet most clinical volvulus occurs in young adults. As a second point it should be mentioned that there are cases in old persons who have anomalies obviously present since birth. Third, Bryant (1921) states that there is more marked ptosis of the right colon (and hence, presumably, greater mobility of the cecum) in females than in males, yet clinical cecal volvulus is recognized to be more frequent in the latter sex.

It seems evident that there are many causes of volvulus. It would be desirable to differentiate between those which merely set up a more favorable mechanical situation and those which actually set the process in motion; unfortunately, in the present state of our knowledge, it is not possible to distinguish between the two. A large number of the causes listed in the literature seem to be of the mechanical variety. Many cases have been reported following events essentially traumatic, among them being exercise, heavy lifting, blows to the abdomen, coughing, jumping, dancing. Pregnancy seems to be an important mechanical cause of volvulus. Dreyer (1911) illustrates the manner in which the rising pregnant uterus displaces a mobile cecum; that such displacement occurs is confirmed by the radiographic studies of Eldering (1932) and Fueth and Obladen (1928). Pratt and Fallis (1927), however, believe that pregnancy causes volvulus not so much by mechanical means as by the abnormal peristalsis accompanying the vomiting of pregnancy. Surgical operations of different sorts have been followed by volvulus, and various kinds of intra-abdominal pathology have been cited as contributory in individual cases. Corner and Sargent (1905) state that the cecum is frequently found in the strangulated or obstructed right inguinal hernia of children and, when distended with gas, is almost always twisted.

There have been many surmises as to the possible etiological rôles of such general factors as race, sex, age, country, and diet. There is little evidence that cecal volvulus is of greater incidence in any particular "race." The case for geographical influence is no stronger. In the early literature many of the victims were German (22 of Bundschuh's 110 collected in 1913). Later, however, Alipow (1925) collected 39 Russian cases, Jacobsen (1924) analyzed 24 cases from Denmark, and several series of cases were reported from other Scandinavian countries. Podlaha (1926) collected 168 cases from Germany, Finland, Russia, Poland, and Scandinavia. Recently there has been an increase in the number of cases from North America, Central Europe, and France (Table I).

On the basis of circumstantial evidence, diet seems to be the most significant general factor.

Pratt and Fallis (1927) and Ohman (1924) note that there was a large increase in the incidence of volvulus in the Baltic states during the Great War, when the diet consisted largely of coarse vegetables. Graham (1926) calls attention to the potato and sour bread diet of Finland and the vegetable diet and heavy eating in czarist Russia. The recent increase in the number of reported cases in America does not seem to have a dietary basis.

Cecal volvulus is conceded to be a disease of young adults. Corner and Sargent (1905) found 50 per cent of cases in the 20 to 40 year group, while Bundschuh (1913) met with 82 of 102 cases under 40 years, and 20 over that age. Faltin (1902) estimated that 71.4 per cent of his cases were less than 41 years and 45.4 per cent in the 17 to 30 year class. This is not in close accord with the anatomical evidence for the age incidence of mobile cecum; von Thun (1913) found that 51 per cent of bodies below the age of 5 had ceca free enough to produce a volvulus, 9 per cent of persons from 5 to 50 and 13 per cent of persons over 50 years of age.

There seems to be a definite sex predilection; males are more often affected with the disorder than are females. Pratt and Fallis (1927), analyzing 150 cases, found males predominating over females in a ratio of 3 to 1, while of Bundschuh's (1913) 110 collected cases, 76 were in men, and of Corner and Sargent's (1905) 57 cases, 42 were in men; Faltin (1902) found that 56 of 79 cases were males. This, again, does not fit in well with the anatomical facts, since it has been generally found that in males the right colon is less free than in females. Thus Harvey (1918) found a right mesocolon in 6 per cent of male infants and in 20.4 per cent of female infants. Wilms (1908) and Klose (1909, 1911) feel that *cecum mobile* is definitely more frequent in the female. Bryant (1921) makes a similar observation. However, Wandel (1903), whose large and carefully studied series demands respect, finds that, as regards ceca free enough to rotate, the proportion is slightly in favor of males.

It is a well known clinical fact that many cases of cecal volvulus occur without assignable cause, particular or general; some begin in the physiological quiet of night. Many cases have a prior history of long standing intestinal complaint. Heavy eating, constipation, and diarrhea have also been noted in cases of volvulus. One must therefore look to physiological maladjustments for the inciting etiology which plays on an anatomical predisposition. True, a mass peristalsis might constitute a true mechanical cause, but upsets of normal peristalsis must be considered physiological in their inception. That the normally placed and fixed right colon is the site of complicated physiological activities, and that disturbances may easily upset their harmony has been emphasized by Homans (1921); such disturbance perhaps results in unusual amounts of putrefaction, in the formation of gas, misdirected peristalsis—leading in the end to distention, kinking, and volvulus. Perazzo, Zavaleta, and Artuso (1938) think that many of the so called traumatic and mechanical causes really act indirectly by setting up pathological peristalses. Harttung (1922) stresses constipation and antiperistalsis as the cause of the actual torsion. McConnell and Hardman (1922) find differences between peristalsis in normally and imperfectly fixed right colons. It should be mentioned that some think a rôle is played by the ileocecal valve in the causation of cecal volvulus (Perazzo, Zavaleta, and Artuso, 1938). Amazing as it may seem, the physiology of this structure is only now beginning to be understood (Wakefield and Friedell, 1941).

CASE REPORT

Mrs. M. N., a white female, aged 71 years, entered Passavant Memorial Hospital August 16, 1938, on the service of Dr. Howard B. Carroll.

On the evening of August 14, at 5:30 p.m., she ate some honey-dew melon and shortly thereafter experienced abdominal distention. At 9 p.m. she began to have generalized abdominal cramps. She took a half bottle of magnesium citrate, which was followed by six watery stools, which did not, however, relieve the pain or distention. On the morning of August 15 she took another half bottle of citrate of magnesia and later a Seidlitz powder. Orange juice, lemonade, and paregoric were taken, but all were vomited. Pain and distention continued. There were two watery bowel movements during the day. The pain, distention, and vomiting continued up to the time of admission on the 16th.

The past history was not pertinent except for constipation of many years' duration. She avoided fried foods, white sugar, white flour and desserts, and had lost 15 pounds in the past year. "Pills" and mineral oil had been used for constipation for many years.

Physical examination revealed a thin woman, with normal pulse and temperature and a blood pressure of 160–90. The head, neck, and chest were normal. The abdomen was markedly distended, tympanitic over the dome, and dull in the flanks. There was no rigidity, but there was generalized tenderness upon palpation. No peristalsis could be seen. The left lower abdomen bulged, and palpation revealed a mass in this locus. The red blood count was 4,580,000; the white blood count, 4,500; the hemoglobin, 14.0 grams. A differential blood count showed 62 per cent polymorphonuclears, 30 per cent lymphocytes, 8 monocytes. The urine contained three plus albumin and some granular casts.

A diagnosis was made of intestinal obstruction, very likely a volvulus. The patient was given intravenous fluids and hot abdominal packs. Her vomiting abated and she passed a fairly comfortable night. There was no stool and she passed no flatus. The distention persisted. On August

17th she was given a barium enema. A large mass of barium was seen in the lower abdomen, with an area of constriction in the lower right colon (Fig. 11). The patient was seen by the senior author on the afternoon of August 17 and was operated upon soon after.

When the abdomen was opened, through a right lower abdominal incision, some blood-tinged fluid escaped from the peritoneal cavity. Loops of ileum were found to be distended. The ascending colon was collapsed, but in the lower abdomen and pelvis could be felt a large, distended loop of intestine. The dilated segment, on delivery from the peritoneal cavity, was made up of the cecum and the first portion of the ascending colon. There was a 360 degree clockwise twist. The dilated loop was some 16 inches in length, 7 in diameter. Its wall was so thin that the contents of the lumen could be distinguished. The loop was untwisted, a catheter implanted, and the cecum emptied of 1½ liters of fluid. A larger tube was then implanted for the purpose of a cecostomy. There was no evidence of necrosis. The gut was replaced and the abdomen closed. The operation was well tolerated. After operation constant gastric aspiration was applied and also suction to the cecostomy tube.

On the following day the patient's condition was excellent, and convalescence went smoothly until the 5th postoperative day, when she seemed weaker and demonstrated dependent edema. Her blood chlorides were found to be 490 milligrams per cent and she was given a transfusion of 500 cubic centimeters of citrated blood.

On the 6th postoperative day she displayed respiratory embarrassment, and oxygen was administered. Her abdomen became distended, and fluids given by mouth did not pass the pylorus. She gradually became weaker and ran a fever up to 102 degrees F. The chest became filled with râles, and she died on August 27, 10 days after the operation.

At autopsy the cecum was found to be of normal size and adherent to the anterior abdominal wall. There was no evidence of leakage around the cecostomy tube. An acute fibrinous peritonitis with ascites was demonstrated, judged by the pathologist to have been due to preoperative soiling. There was also an acute bilateral fibrinous pleuritis with hydrothorax, subtotal pulmonary atelectasis and other irrelevant findings such as early portal cirrhosis, enlargement of the spleen, chronic cholecystitis with cholelithiasis, and arteriosclerosis.

There are several points of interest in the case. One is the advanced age of the patient; though by no means the oldest case on record, this is one of the most aged. Second, is the fact that a preoperative diagnosis was made on the basis of clinical findings. Third, is the attributability of the fatality to the 2 day delay in seeking medical aid and the additional delay in resorting to surgery. This case serves well to stress the point that volvulus of the cecum, in its usual form, is an acute surgical emergency. The presence of a distended cecum is a constant menace; through its thin walls contamination of the peritoneum can easily take place, as occurred in this patient, to prejudice seriously the success of inevitable operation.

The direction of torsion in this case was definitely clockwise in the sense defined by Beeger (1923) and Graham (1926). The anatomical mobility of the cecum was clearly evident. The loop was filled with fluid, not with gas, as Weinstein (1938) and Homans (1921) have assumed to be the case, because of the colonic anaerobes growing in an oxygen deficient milieu. In the current case, however, there was a narrow lumen at the site of the twist, which allowed barium introduced into the colon to enter the twisted loop (Fig. 11).

The inciting etiology in this case would seem to be pathological peristalsis, whether before or after the intake of cathartics cannot be stated. The diagnosis was made on clinical grounds, but confirmed by radiological examination. A scout film of the abdomen and a barium enema are of great diagnostic assistance. If a small lumen is present the volvulus can be directly visualized. If torsion is complete, the point of obstruction shows up as a cone-shaped, smooth shadow. In such event, the presence nearby of a large dilated loop of bowel suggests cecal volvulus.

Prompt surgical intervention is necessary, as emphasized by the case of Valentine and Kinnear (1937) in which death occurred in 5 hours. The presence of vascular obstruction sufficient to cause necrosis cannot be determined unless the abdomen is opened. Leakage from the thin walled and distended cecum is a source of constant danger. The procedure to be utilized varies in the hands of individual surgeons. Many operations have been recommended, but, since these patients are usually debilitated, the simplest possible measure should be chosen. Untwisting and cecostomy constitute the conservative procedure in cases in which the gut is viable. In patients having necrotized bowel, the involved sector can be exteriorized. Resection is used but would seem too severe an operation for any patient not in unusually good condition. The situation is quite different with regard to chronic or partial volvulus. In this contingency it is permissible to restore normal peritoneal relationships by some of the cecoplastic procedures.

SUMMARY AND CONCLUSIONS

Over 300 cases of volvulus of the cecum have been reported in the international literature. It therefore follows that cecal torsion is not a mere surgical curiosity, but a possibility which should be kept in mind in the differential diagnosis of disease presenting in the right lower quadrant of the abdomen, and in the differential diagnosis of intestinal obstruction. The literature pertinent to the subject is briefly outlined.

It is proposed that volvulus of the cecum be defined as torsion limited to the cecum and adja-

cent terminal ileum and ascending colon, as suggested by Gatellier, Moutier and Porcher (1931). It is further proposed that the direction of twist be noted as clockwise or counterclockwise as referred to an hypothetical watch placed dial up on the patient's abdomen, as originally suggested by Beeger (1923) and Graham (1926).

In 125 normal adult cadavers studied consecutively by the present authors it has been demonstrated that in 11.2 per cent the cecum is mobile enough to allow the development of a volvulus. A survey of the literature indicates that 10 to 15 per cent of ceca are free enough to undergo torsion. In the present series 10.4 per cent of terminal ileums were found to be fixed; of these 38.5 per cent were associated with free cecum, and in these cases the attached ileum could serve as a hub were the ileocolic part of the digestive tube to revolve.

The anatomical arrangement which best predisposes to cecal volvulus is believed to be one in which the cecum is free and the ascending colon fixed somewhere along its vertical course. It is noteworthy that many accounts of clinical cases describe a band which binds down the ascending colon. Of 8 instances of this anatomical type encountered in the present authors' series of 125 specimens, 3 displayed some degree of torsion. The mechanism of volvulus varies greatly, but seems to depend chiefly upon the anatomical relationships and upon the position of fixed point or points for twisting.

The inciting etiology of this disease may be purely mechanical, or may be due to as yet incompletely understood physiological faults in the complex functioning of the right colon.

A case of cecal volvulus is reported. A study of this case serves to emphasize the necessity for prompt surgical care, and the importance of early examination by roentgenographic means. The authors suggest that cecostomy or exteriorization is the procedure of choice in acute cases, final selection depending on the viability of the bowel. Resection should be reserved for patients whose condition is very good. Cecoplastic procedures are permissible for chronic or partial volvulus.

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HAZARDS OF FIRE AND EXPLOSION OF ANESTHETIC AGENTS

III. In the Presence of Diathermy

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THIS report, the third in a series on the fire and explosion hazard in modern anesthesia, is best viewed as a logical development of our previous reports. It is especially related to the paper on cautery ignition (3), which we recommend for study before reading this report.

The application of high frequency electrical currents to surgery is widespread and increasing; it is practically indispensable in some phases of modern surgery, especially neurological and genitourinary surgery. Therefore, anesthetists must accept the presence of electrosurgical apparatus in the operating room and must adapt their methods to this hazard.

Paralleling the increased use of electrical instruments in the presence of anesthetic agents and equipment is the decreased use of open ether and chloroform volatilized with air, and the greater utilization of semiclosed and completely closed methods of administration of ether, ethylene, and cyclopropane, with high concentrations of nitrous oxide or oxygen, or both. While these changes have been of great value in diminishing intraoperative and postoperative morbidity, they have, unfortunately, augmented the likelihood of serious injury to the patient and the surgical team exposed to an anesthetic combustion. It is more important than ever before to prevent anesthetic ignition, especially the entirely preventable types associated with electrical apparatus.

A marked discrepancy and a lack of unanimity in anesthetic practices exist with regard to these dangers. Even in hospitals with otherwise progressive departments of anesthesiology, we have found unsafe techniques in use. Many have adopted inadequate compromises as a result of incomplete understanding of the details of the hazard, e.g., barring ethylene and cyclopropane but allowing ether (17), or forbidding combustible inhalation anesthetics in head and neck electrosurgery but permitting them in surgical diathermy employed at more remote points of the body or extremities (5).

It is high time that there be established a universally accepted standard of safe practice of anesthesia with diathermy. We believe that our studies have secured sufficient information to make this possible, and more, to make it convincing.

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ELECTRICAL DATA

The basic information about combustible anesthetics has been presented in detail in foregoing reports (3, 4). All that is necessary, we believe, to secure understanding and agreement with our opinions on this type of electrical hazard is a presentation of the electrical aspects of high frequency apparatus as they are related to the possibility of igniting a combustible inhalation anesthetic mixture.

The heat necessary for ignition—182 to 517 degrees C. (3) may be considered present whenever a visible or audible spark is produced. For practical purposes, this is a necessary and safe rule even though it might be shown that there are degrees of sparking which cannot ignite anesthetic mixtures (we do not know of any such proof). When the surgical diathermy is employed, sparking or arcing may appear in five zones: (1) at the active electrode during fulguration, coagulation, or cutting; (2) within the cabinet of the apparatus if the machine has a spark-gap or defective insulation; (3) at the foot or hand switch controlling the make and break of the circuit; (4) at the wall plug socket during the make or break of the connection; (5) *this is the one source of sparking usually overlooked*—at many scattered and unpredictable points where a high frequency current or induced current jumps an air gap formed between the patient (charged by the high frequency electricity coursing between the two electrodes) and a grounded conductor or any conductor of sufficient electrical capacity to accept a charge. Such a conductor may be a nearby grounded or ungrounded machine or person.

We must consider each of the five zones in greater detail with regard to explosion protection from the sparks arising in each zone.

1. The active electrode always produces a spark or arc whether the high frequency current is adjusted for fulguration and coagulation (which are visibly associated with arcing) or for cutting. This knife-like action is performed, not by a hot electrode, but by an arc which forms ahead of the electrode and which separates the tissues by volatilizing them (2). The danger arising from the arcing active electrode is as obvious and as localized as that of the hot-tipped actual cautery. All the rules suggested in our earlier report (3) on the cautery may be applied here. We refer the reader to this paper for details.

2. The sparks in the cabinet of the apparatus may be caused by the multiple spark-gap frequently used to produce the high frequency oscillating current. This source of sparking is absent in the type of equipment which substitutes radio vacuum tubes for the spark-gap mechanism. Another source of sparks may arise from faulty or worn insulation or loose contacts. All of these internal machine sparks may be rendered innocuous by following the same precautions as have been described for the active electrode or actual cautery. Another method of protection that has been employed is the placing of the machine outside of the operating room and using very long lead-in wires to the electrodes.

3. The sparking at the foot or hand switch is an obvious hazard easily removed by enclosing it in a bag through which it may be operated, similar to the suggestion made for the fluoroscopic foot switch.

4. The plug-socket hazard at the wall connection may be avoided by inserting the plug before the start of anesthesia and removing it only after the anesthesia has ended and the room well ventilated. To prevent accidental disruption of the connection, one should use a locking type of wall socket (21). Of course, if the socket is located outside of the operating room, the above precautions are unnecessary.

5. The scattered and unpredictable type of sparking mentioned before in zone 5 cannot be surely and safely prevented, as the following consideration explains. Arcs may be produced in the presence of high frequency generators under conditions that would be absolutely safe from any other form of electrical spark. There are two reasons for this: (a) Arcs may be drawn from a high frequency conductor by a grounded conductor or by any conductor of relatively high capacity, e.g., a human body, even if it is perfectly insulated. In the case of an insulated body, it is continually charged and discharged by electromagnetic induction and if the distance is small, this electromagnectic stress will cause ionization of the air in between to the extent of forming a continuous arc. (b) An otherwise well insulated conductor may acquire an induced high frequency voltage by being near a high frequency conductor. Arcs may then be drawn from it very easily as described in (a). Many substances which are poor conductors or even good insulators to direct current or low frequency alternating current are good conductors of high frequency electricity. All of these special characteristics observed in using high frequency increase in proportion to the frequency; and the frequencies employed in surgical diathermy are very high.

This information shows how difficult it is to limit the path of high frequency electricity and the possible points of arcing. Even with the inactive electrode on the sacrum and the active electrode at the urethra, the currents are traversing all parts of the patient and are not entirely confined to a narrow path lying between the electrodes. "A current diffuses itself more or less throughout the body" (11). This devious route is followed partly because of the varying electrical resistances of the structures in its path. No matter how far the electrodes may be from the mask, the hazard of arcing in or near the inhalation system is a constant threat.

The prevention of this diffuse type of sparking is possible theoretically by connecting the patient to all objects and persons likely to approach him closely. To offset the increased hazard of electric shock introduced by this greatly increased circuit and capacity, it would be necessary to add a high resistance barrier between each person and any likely grounding contact. It should be apparent how difficult this would be. Much more so than the Horton system (9) of intercoupling described for the prevention of electrostatic sparking. For, in addition to the group connected by the Horton intercoupler, (operating table, patient, anesthetist, and anesthetic apparatus) it would be necessary to include in the circuit all of the surgical teams and instruments which might draw a spark from the electrically connected patient and group in the immediate vicinity of the anesthetic inhalation system.

It should be evident why we consider the use of a combustible inhalation anesthetic mixture as entirely unsafe in the presence of electrosurgery anywhere on the patient. Even with precautions theoretically possible but never applied and highly impracticable, the practice is not as safe, more cumbersome, and less practicable than the use of noncombustible anesthetic methods and techniques. The progress of anesthesiology in the di-

rection of regional blocks, spinal anesthesia, rectal basal narcosis, and intravenous barbiturate anesthesia now makes it safe and feasible for a trained anesthetist to administer a noncombustible anesthetic whenever high frequency currents must be employed.

Our personal experience is worth citing as typical of the necessary and practicable adjustments in anesthetic methods safe for use in the presence of x-ray and diathermy apparatus. In our early years, we were fortunate in our ignorance to have used, without mishap, ether-oxygen-nitrous oxide and cyclopropane-oxygen for fluoroscopic surgery and surgical diathermy in various parts of the body, ranging from the breast to the cervix. With further education and experience, we have learned to discard these dangerous practices and to substitute noncombustible methods without serious difficulty. An increased use of spinal and other regional blocks, intravenous barbiturates and rectal basal narcotics combined with nitrous oxide-oxygen or regional blocks has enabled us to supply noncombustible anesthesia whenever the surgeon has desired to use the x-ray or diathermy. And at no time were we ever doubtful of the safe control of the depth of the anesthesia. Our most common occasions for changing a combustible inhalation anesthesia to a noncombustible technique have occurred in radical breast and neurological surgery. In both, we have been well pleased by the supplemental use of minimal amounts of intravenous barbiturates injected into the tubing of the infusion usually started with radical breast and neurological surgery. Simultaneously, the combustible agent is removed from the apparatus and "washed out" of the patient. The inhalation apparatus is used to supply nitrous oxide-oxygen with relatively large amounts of oxygen (20 to 25 per cent) and to provide an accurate indicator of the respiratory excursions. We have found this combination of minimum doses of pentothal sodium with optimum oxygen-nitrous oxide the answer to most of our problems of supplying noncombustible anesthesia in the presence of diathermy, when spinal or regional block was impracticable.

CLINICAL DATA

We have found published warnings (7, 8, 16, 18, 19, 22) against the use of diathermy apparatus with inflammable agents as far back as 1924. Through the 16 years, it has been repeated again and again. Yet explosions and deaths have been caused by the practice even up to the present; and the hazard is being repeatedly tempted in very many hospitals, even by some of the largest. We believe that the reasons for this continued violation of safe practice are four; one or more of these accounting for the persistence of the dangerous combination in different institutions: (1) Ignorance—of the physics and chemistry of the subject and therefore of the reality of the hazard; (2) indifference—to the hazard because of past "blind" good luck and because of unawareness of the catastrophes experienced by others; (3) inflexibility—of available methods of anesthesia because of lack of versatility and training in the anesthetist, forcing the use of combustible anesthetics in hazardous circumstances; (4) conflict—of opinion among surgeons, anesthetists, and diathermy manufacturers, fostered by the lack of an official and unequivocal censure of the unsafe practice.

In the literature and in our discussions with many anesthetists and surgeons, we have noted an almost universal disregard or oversight of the "diffuse sparking" tendency of high frequency currents, a fact long known to physicists. We have found only two statements alluding to this feature, but both without explanation. Size (20) has stated "at the present time there does not seem to be any certain way of guarding against miscellaneous sparking from this procedure," i.e., diathermy. The Minister of Health for England and Wales, in a memorandum (14) on the use of electrical apparatus in the presence of an inflammable anesthetic, pointed out that the patient, under an electrical potential while in a surgical diathermy circuit, may allow a spark to jump from himself to the operating table or anesthetic apparatus.

The elimination of the first three of the reasons stated above, for the persistence of the unsafe practice of mixing diathermy with inflammable anesthesia, is entirely dependent on the universal elevation of the standards of education and supervision of anesthesia and anesthetists. Fortunately, this is rapidly, but not rapidly enough, becoming a reality.

Most authorities condemn the practice under discussion, but we have found several writers who have permitted the loophole to remain, through which the erring anesthetist may escape condemnation. These writers, usually on very inadequate grounds, have indicated that ether inhalation is permissible with diathermy. For example, Mock stated "The anesthetic of choice in these cases of goiter is 0.5 per cent procaine hydrochloride used locally. With this anesthetic no precaution need be taken on account of the electrical current. Nitrous oxide may be used without fear of an explosion, and ether can be used. In the lat-

ter 2 cases, a wet flannel roll is placed just below the lower edge of the mask and further protection against the fumes of the ether reaching the electric spark is provided by a rubber apron placed over the anesthetic frame and held tightly by clips against the skin of the cheeks and chin. If a general anesthetic is necessary, rectal ether anesthesia, as in one of my cases, may be used. In all but one of the 15 cases in this series, local anesthesia was used." It is apparent that this author was recommending ether inhalation with electrosurgery of the thyroid gland without ever having used it.

Even the discoverer of the clinical usefulness of ethylene for anesthesia has committed the error of advising a combustible inhalation anesthetic with surgical diathermy. In 1924, Luckhardt and Kretschmer reported their use of ethylene anesthesia in 13 cases of fulguration of the urinary bladder and 1 case of carcinoma that received diathermy. In this article, they stressed the fire and explosion hazard of flame, cautery, and electric sparks. Then they described the careful placing of the spark-gap apparatus at a distance from the patient, with the machine cover kept shut and the lead wires to the electrodes drawn through holes drilled through the walls of the cover. Yet they failed to recognize the danger of the sparking active electrode and the greater threat of "diffuse sparking" from any part of the patient. No explosion occurred even though this was in the days of only semi-open administration of ethylene. This is an excellent example of the fact that failure to cause an explosion by violation of the rules of explosion prevention cannot be used as evidence of the harmlessness of the bad practice. An explosion is the result of the coincidence of many predisposing factors, of which the absence of any one may prevent the accident favored by the many other favorable influences.

We have been surprised to find Guedel allowing "Ethylene, properly managed, may be used in electric fulguration within the bladder if the air bubble above the water is held to minimal size and the fulguration spark is not permitted to reach the bubble" (6).

Kovacs (12), in his authoritative textbook on electrotherapy, has contributed to the indecisiveness of the warning against using diathermy with ether by describing its use in one paragraph, but, in the next, saying "since, however, there have been occasional serious accidents resulting from ignition and explosion of ether vapor it is better to avoid its use when possible."

Kelly and Ward, in their textbook entitled *Electrosurgery*, repeatedly advised the use of the hazardous technique of interrupted open ether anesthesia for oral and other types of surgical diathermy, stating that the risk is slight with proper precautions, i.e., the patient exhales a few times and all ether-soaked materials are removed. While this was their most common method of general anesthesia, probably because of a lack of trained anesthetists, they admitted that "rectal anesthesia administered by a trained anesthetist is the method par excellence."

Many manufacturers, in the commercial literature accompanying their diathermy apparatus (17), have warned against the use of ethylene but advised that ether might be used with only the precautions of an ether screen and wet towels. One of the leading manufacturers so poorly understood the ignition possibilities of diathermy, that he considered the sparking hazard present only in the spark-gap type of machine and absent in the vacuum tube models.

The precautionary steps necessary to allow the change-over from a combustible anesthetic to a noncombustible one for use with diathermy are the same as are those which have been advised and described for cautery surgery (3) about the head after a combustible inhalation agent has been used.

There are three other varieties of hazard of special interest to the anesthetist when the diathermy is operated in the surgery: (1) The active electrode can ignite an inflammable cleansing or antiseptic fluid painted on the surgical field as it did in 3 cases. In this respect, the cautery and diathermy present the same problems. The field and drapes prepared with an inflammable cleanser or antiseptic should be thoroughly dry before the active electrode is applied, or better yet, a noncombustible fluid should be used. (2) There is a type of accident peculiar to bladder fulguration during which hydrogen may be liberated by the decomposition of the irrigating water within the bladder. The hydrogen rises to the dome of the bladder, mixes with the air bubble, and is subject to explosion whether or not an inflammable anesthetic agent is in use (6). (3) The last type of danger is that of electrical short-circuiting with the resulting effects of electrical shock and sparking. These are possibilities which are ever present with electrical apparatus of any type receiving its source of power from a house current (110–220 volts). The main line of current may reach the operator or patient or by stander accidentally or intentionally in circuit with a part of the apparatus which has become "live" because of a break in the insulation within the machine or a defect in a condenser. This allows a leak of the main 110

to 220 volt current to a metal part that is usually insulated or to the secondary circuit which normally carries only a very small amperage. If "grounding" is in use, the electrical shock and the short-circuit spark are increased. The presence of a megohm resistance, as in the Horton intercoupler, between the "ground" and the person "grounded" eliminates the possibility of shock to those in the intercoupled group but does not prevent short-circuit sparking. The surgeon or a nurse, who are usually not included in the intercoupled group, may still be badly shocked or killed if he or she is standing in leather-soled shoes (which are conductive) on a "grounded" floor.

To prevent short-circuit sparking or electrical shock, it is necessary to check regularly the insulation of the diathermy equipment (in fact, all electrical apparatus on a house current) by means known to every electrician with the aid of a megger. It requires vigilance, circumspection, and repeated inspection to employ safely the modern equipment of surgery. These virtues are rarely used in most operating rooms until after the first accident has been experienced.

CLINICAL DATA

We have recorded 20 cases of fires and explosions ignited by diathermy apparatus. Three cases involving ether-air caused no injury; 8 cases of ether mixed with high concentrations of a source of oxygen (nitrous oxide or/and oxygen) resulted in the death of 2 patients, the serious injury of a third patient and 3 bystanders, and the slight injury of a patient and 2 bystanders. One case of nitrous oxide-oxygen containing an unknown combustible seriously injured the patient. Two cases of ethylene-oxygen caused the death of 1 patient and in another the rupture of the urinary bladder with recovery following repair. Two cases of cyclopropane-oxygen occurred, with the death of 1 patient. There were 3 cases of surgical field fires: alcohol ignited in 2 with the death of 1 patient, and ether ignited in 1 instance with death of the patient.

The igniting spark appeared at the active electrode, where the threat is exactly identical with that presented by the actual cautery tip, in 14 cases. The detailed consideration of this type of obvious hazard would be only a repetition of our discussion of the cautery hazard, to which the reader is referred.

In the remaining cases, the igniting spark occurred in unexpected and unpredictable places in or near the respiratory path of the combustible anesthetics although both the inactive and active electrodes were deliberately and probably effectively kept out of contact with the gases. In these cases (definitely in 4 cases, and probably in 2 cases) the spark was of the type which is less obvious and more difficult of prevention, namely, the "diffuse sparking" which has been described in paragraph 5 of the electrical data presented in the early part of this paper.

SUMMARY AND CONCLUSION

We have considered in detail the electrical basis of all sparking or arcing during the use of high frequency apparatus. The prevention of all sparks is impossible. The localization of the hazard to one restricted zone, as is possible with the actual cautery, is practically impossible. No matter how far from the mask the electrodes are placed, there is serious danger of spark ignition of a combustible inhalation anesthetic mixture. In view of the relatively narrow field of use of surgical diathermy and because of the practical impossibility of spark prevention during diathermy, we have reached the conclusion that combustible anesthesia is contraindicated by the surgical need for diathermy in any part of the head, neck, body, and extremities.

We have directed attention to the other hazards of surgical diathermy in the operating room, namely, surgical field fires, fulguration-produced explosions of hydrogen in the urinary bladder and electric shock and sparking resulting from short-circuits in defective apparatus.

Our study forces us to conclude with the bald statement:

Anesthetic fires and explosions ignited by diathermy, like those due to x-ray apparatus, are completely preventable only by the use of noncombustible anesthetic methods. Failure to use such methods in the presence of diathermy is an admission of inability to maintain the standards of safe anesthesia which have long been advocated by many authorities, which are here demonstrated as necessary, and which are now practiced in the better departments of anesthesia and surgery.

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EDITORIALS

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BACKACHE

THERE is an increasing tendency in this country to ascribe all lame back conditions to a ruptured intervertebral disc resulting in a herniation of its nucleus pulposus into the spinal canal, and when no evidence of such a lesion can be demonstrated by examination or by operation, there is a further tendency to make a diagnosis of a thickened ligamentum flavum. It must be remembered that pain in the back is still pain, and as such is only a symptom of many conditions which may exist in the back itself or regions outside the back, e.g., peptic ulcer, kidney and pelvic lesions, Hodgkin's disease, diseases of the blood (leucemia) and general infections. One of the most prominent and early symptoms of small pox is severe backache.

Low back pain above, or in combination with, radiating pain, especially along the course of the sciatic nerve, may be present in a great many instances in which there is not a shred of evidence by x-ray or by myelogram of any local intraspinal lesion. It would be just as logical to assume that all headaches are due to intracranial lesions. There are no typical physical signs of a herniated nucleus pulposus. Certainly a diminished knee jerk or absent ankle jerk is not pathognomonic, since these alterations may be seen in cases in which there has been a prolonged sciatica from many other causes. Furthermore, the removal of a herniated nucleus pulposus or a thickened ligamentum flavum does not always relieve or cure the lame back.

There are many conditions which may produce this so often distressing and even agonizing symptom, e.g., occupational attitude, sprains, compression fractures, malignancy, arthritic infections, local and general disturbances in the abdominal, pelvic, and retroperitoneal regions, pregnancy, relaxed abdominal walls after pregnancy, mechanical conditions of the extremities such as tilted pelvis, unilateral short leg, foot strain, contracted fascia lata, and bad posture. There is a large group of patients who may have severe pain radiating down the sciatic nerve. This pain may be alternating and the patients may show no clinical signs whatever of low back trouble. They are apt to be fascial, not "muscle bound."

On the other hand, a patient may have the severest of lame backs without any evidence by x-ray or other tests of any abnormality in his vertebral column, and the reverse of this is true; he may exhibit by x-ray marked congenital abnormalities or severe osteoarthritis of the spine and never have a lame back. When a patient does have a lame back in the presence of such abnormalities, why does he ever recover when these remain the same? There is plenty of evidence that recovery does take place and often without a recurrence of

symptoms. If this is true, then, the answer must be found elsewhere. Certainly in the face of so much evidence, it cannot be assumed that there is any single condition which will give a 100 per cent answer. The diagnosis of a herniated disc is not easy; it is a diagnosis which grows on one who takes care of a lame back which does not become relieved under proper care and supervision and after competent consultation.

In studying a patient who presents himself with a backache, it may be assumed that no matter what the final diagnosis is, the reason for the pain is a distortion or alteration in the normal physiological curves of the spine and that in treating the underlying pathological condition, one must not lose sight of this fundamental principle.

The malingerer must not be forgotten. He may be an intentional one, or he may be an exaggerator who has a mild lame back but who wants everyone to know that he is in a bad way. The diagnosis of lame back in such individuals will test all the resources of the physician, and he must beware particularly of the possibility of making a mistake in arriving at his conclusions.

FRANK R. OBER

THE SURGEON'S LIBRARY

REVIEWS OF NEW BOOKS

IT is estimated that 40 to 50 per cent of all disease in man is due to infection. Approximately 250 living agents of animal or vegetable origin are known to produce disease: at least 56 different bacteria; 8 spirochetes; 21 ultramicroscopic viruses; 63 molds, yeasts, actinomyces, and pathogenic fungi; 16 protozoa; 31 helminths; and, about 51 anthropods. Infection involves two living entities: the infectious agent and the host. It is the balance between them which determines the outcome. A clinical understanding of the mechanisms of infection on one hand and of natural resistance and acquired immunity on the other is of fundamental importance in the prophylaxis and treatment of disease. On this thesis, Kolmer and Tuft have developed *Clinical Immunology, Biotherapy and Chemotherapy*,[1] which is composed of two parts.

Part I covers the general aspects of infection, immunity, biotherapy and chemotherapy while Part II is given over to the clinical applications of these principals which concern the diagnosis, prophylaxis, and treatment of disease.

The difficult and often confusing subject of immunology is presented in a clear, concise, orderly manner. A chapter is devoted to each of the following subjects: active immunization and vaccine therapy; passive immunization and serum therapy; bacteriophage therapy; methods of diagnosis and treatment of allergy; blood transfusion therapy; nonspecific protein therapy; and chemotherapy.

In Part II infectious diseases are grouped under suitable chapters, and emphasis is placed upon the immunological aspects of disease and treatment suggested along these lines. Such information is of greatest value to the student of medicine who has a fundamental knowledge of these diseases, as no attempt is made to present a complete clinical picture or to suggest general therapeutic measures. In most instances the authors have adhered to their subject and they have written with unquestioned authority.

The authors should be commended for editing this mass of material and correlating these related subjects in such an agreeable text. There is no other book known to the reviewer which contains such a wealth of material pertaining to the therapy and practice of immunology. Each chapter has a comprehensive summary and, in addition, to each a list of valuable references is appended.

HOWARD B. CARROLL.

[1]CLINICAL IMMUNOLOGY, BIOTHERAPY AND CHEMOTHERAPY IN THE DIAGNOSIS, PREVENTION, AND TREATMENT OF DISEASE. By John A. Kolmer, M.S., M.D., Dr.P.H., Sc.D., LL.D., L.H.D., F.A.C.P., and Louis Tuft, M.D. Philadelphia and London: W. B. Saunders Co., 1941.

THE book entitled *Surgical Diseases of the Spinal Cord*[2] by Elsberg is far too comprehensive to admit a discussion of any one specific feature of its many contents. It is in a sense a source book, yet a book which reads as easily as a good novel, and throughout the book one finds morsels of digression, such as a note on the history of laminectomy in Chapter XV, which enliven and enrich the text for the less intent reader. This work is noteworthy for its solid and conservative honesty, its lack of overstatement, and its easy avoidance of dogmatism. This is true because it is Dr. Elsberg's forthright statement of up-to-date factual data molded around his profound knowledge of diseases of the spinal cord resulting from his own vast personal experience. To illustrate this point one need but to mention his opinions concerning the possible difficulties in the operative exposure of a ruptured intervertebral disc. The author certainly labors under no illusions, and he advocates the application of only solid surgical principles.

The book is beautifully printed. It is well organized as to content, it is well indexed, and the many simple half-tone illustrations enhance its attractiveness. Chapter X, concerning the diagnosis of cord tumors by clinical features at different levels, typifies the uncomplicated, direct, and effective style of the author. While it is definitely Dr. Elsberg's book, the chapters on roentgenology and pathology of diseases of the cord by Drs. Dyke and Wolf are worthy of the prominent place which they are given in the book.

Many contemporary surgeons will agree that Dr. Elsberg represents in relation to disease of the spinal cord that which Dr. Cushing did in relation to intracranial disease. As Cushing's contributions have been as yet but little enlarged and improved upon, even so, in the opinion of this reviewer, the American literature contains no current book surpassing this one in genuine reliability for student and clinician alike.

JOHN MARTIN.

TO surmount the difficulties of making clear to beginning medical students the anatomy and function of the nervous pathways is one of the chief goals of every teacher of neuroanatomy. The subject must be presented in a simple fashion if it is to be remembered, and in simplifying it much detail, and possibly some accuracy, must be lost. Rasmussen is perfectly conscious of the shortcomings of a

[2]SURGICAL DISEASES OF THE SPINAL CORD, MEMBRANES, AND NERVE ROOTS; SYMPTOMS, DIAGNOSIS AND TREATMENT. By Charles A. Elsberg, M.D. With chapters by Cornelius Dyke, M.D., and Abner Wolf, M.D. New York: Paul B. Hoeber, Inc., 1941.

greatly abbreviated text, such as his present book is.[1] He recognizes the inadequacy and dogmatism of charts and drawings. But his aim has been to make available to the student, in the limited time allowed for the study of neuroanatomy, a dynamic understanding of the nervous system. That is, he is anxious to correlate function and structure in as simple a manner as possible, preserving accuracy and aiding memory.

This small, well indexed book is but 65 pages long, and it contains 28 diagrams or charts. The text is very brief, concise, and free of any discussion or enlargement upon the simple statements of fact. Many of the diagrams appear confusing at first, with their mass of labels, dotted lines, and anatomical sketches, yet with a little patience the reader readily masters the object of the figure. Such charts as Figures 3 and 8 are especially useful.

There can be no doubt as to the practicability of the book. That it is anything but a complete course in functional neuroanatomy and that its use by no means obviates the necessity of a "standard" text is entirely apparent, but these facts would be agreed to by the author himself. By his other works the author is recognized as a direct and practical person, and in this book he has accomplished his purpose in successfully condensing into a form for practical use a great mass of otherwise cumbersome material. JOHN MARTIN.

THE fact that Bell has published a fourth edition of *A Text-Book of Pathology*[2] in 11 years testifies to its popularity. Comparison of the four editions shows a continuance of the brief and direct style of writing. There is, also, still evident the didactic principle of direct exposition without argument, which sticks closely to well accepted beliefs of today. It is probable that, for the average student, such presentation drives home a solid subject basis. The reference lists given are pertinent and well trimmed.

The sections of three of the six original contributors have been taken over by Bell as editor. The method of presentation and material in these sections remain practically unchanged.

Basically, pathological anatomy remains much the same through the years, and the question might well be asked "Why bring out new pathology texts or revise old ones?" It is evident that interpretation of observations is influenced strongly by the state to which medical knowledge has progressed. Recognition of new diseases, or application of new principles of etiology or of diagnosis or treatment to old diseases must continually change our perspective. Bell's *Pathology* appears to have kept abreast of the times,—quite solidly. HAMILTON R. FISHBACK.

IN a book for the undergraduate student,[3] Ritchie stresses the fundamental principles of surgery but leaves the phase of operative surgery to the more voluminous surgical texts. As he states, "it reflects the attitude and practice of the Surgical Department of the University of Minnesota Medical School." Several chapters in the book were written by other members of the staff of the medical school.

This single volume follows the trend of the more voluminous texts except that the material presented is more concise and always to the point.

An interesting but brief history of the development of surgery from the Paleolithic period of 25,000 years ago to Murphy (1916) and Halstead (1922) gives an interesting start to this volume.

The chapter on anesthesia is up to the minute and a valuable adjunct. One of the most difficult problems in therapy for the student to understand—that of water balance—is presented simply and in a manner easily understandable by the novice. Chapters worthy of special mention are those relative to peripheral nerves, blood and lymphatic systems, fractures and dislocations, and the endocrine glands. The outline of urology will be a welcome adjunct to the medical student.

Much material is "crammed" into a single volume, much of which is in outline form which may have its virtues as well as its shortcomings for the average student. For a birds-eye view of surgery, this is an excellent volume. EARLE I. GREENE.

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[3] ESSENTIALS OF GENERAL SURGERY. By Wallace P. Ritchie, M.D. St. Louis: C. V. Mosby Co., 1941.

BOOKS RECEIVED

Books received are acknowledged in this department, and such acknowledgment must be regarded as a sufficient return for the courtesy of the sender. Selections will be made for review in the interests of our readers and as space permits.

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